FISCAL YEAR 1983
DEPARTMENT OF ENERGY
BUDGET REVIEW
(Magnetic Fusion Energy)

HEARINGS

BEFORE THE

SUBCOMMITTEE ON
ENERGY RESEARCH AND PRODUCTION

OF THE

COMMITTEE ON
SCIENCE AND TECHNOLOGY
U.S. HOUSE OF REPRESENTATIVES

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FISCAL YEAR 1983 DEPARTMENT OF ENERGY BUDGET REVIEW

TUESDAY, MARCH 23, 1982

House of Representatives,
Committee on Science and Technology,
Subcommittee on Energy Research and Production,
Washington, D.C.

The subcommittee met, pursuant to recess, at 9:01 a.m., in room 2325, Rayburn House Office Building, Hon. Marilyn L. Bouquard (chairman of the subcommittee) presiding.

Present: Representatives Bouquard, Wolpe, Volkmer, Lujan, and Morrison.

Staff present: John V. Dugan, Jr., staff director; Harlan Watson, technical consultant; and Joyce Gross Freiwald, Republican technical consultant.

Mrs. Bouquard. The subcommittee will come to order. Before we begin, I do ask unanimous consent that pursuant to House rules, television and other recordings of today's hearings be permitted.

Hearing no objection, so ordered.

Good morning, ladies and gentlemen. The subcommittee meets today and tomorrow to consider the Department of Energy's magnetic fusion energy program. Today we are going to receive testimony from the Department of Energy on their budget request, and tomorrow we will hear from industry representatives and other interested individuals from the fusion community.

Today I do want to welcome the Director of the Office of Energy Research, Dr. Alvin Trivelpiece, and the new Associate Director of the Office of Fusion Energy, Dr. John Clarke. I do want to congratulate Dr. Clarke on his new position, and I want to commend Dr. Trivelpiece on his excellent choice. I am delighted that John is going to be making his debut today, and I hope he won't feel mistreated by us despite the differences that we do have on the budget.

Prior to our DOE testimony, we are going to be hearing from Hon. Pete Stark of California about his concerns for the reduced funding level proposed for the Magnetic Fusion Test Facility, the MFTF-B. Pete, I do share your concern about the delay in this project, and I hope that we will be better able to assess the impacts of these cutbacks after today's hearing.

For the second year in a row, the Department of Energy has submitted to the Congress a budget which fails to meet the letter and spirit of the Magnetic Fusion Energy Engineering Act of 1980. While this subcommittee recognizes the necessity of constrained budgets during this period of economic uncertainty, it is concerned about the program's continuing emphasis on the scientific aspects and the continuing neglect of significant engineering-development activities. We are particularly interested in hearing the Department's assessment of the program's technical readiness to move into a significant engineering-development phase, and the current and the planned activities addressing the Fusion Engineering Device. Also of interest is the Department's perception of the appropriate timing and the level of significant industrial involvement in this program, as well as the status of international activities in magnetic fusion, and the Department's plans to increase international cooperation.

Finally, I want to note the subcommittee's concern that funding has either been reduced significantly or it has been eliminated for several projects which we have fully supported in the past, for instance, the MFTF-B which Pete is going to address, our EBT-P project, as well as the FMIT facility in Hanford. We hope that the Department will explain to us in some detail why it felt that these worthy projects, so important to a rational assessment of fusion's potential as a reliable energy source, were not funded at an appropriate level.

Congressman Stark, Al, and John, I welcome you here today, and I look forward to hearing your testimony.

Pete, we welcome you, and you may proceed.

STATEMENT OF HON. FORTNEY H. (PETE) STARK, JR., A MEMBER OF CONGRESS FROM THE STATE OF CALIFORNIA, ACCOMPANIED BY TAMRA BARTELS, LEGISLATIVE ASSISTANT

Mr. STARK. Madam Chairman, thank you very much. It is an honor to be before your committee. I would like to identify Ms. Tamra Bartels from my staff who spends a good bit of her professional time trying to assist the Lawrence Livermore Lab which is a prominent research laboratory and I am proud to represent it and most of its almost 7,000 employees.

More than that, I stand before you as an example of what can happen when one slows down funding of technical research and experimenting. I was once an engineer. I took some time out to do a whole host of other things, and I am probably beyond repair.

Mrs. BOUQUARD. I imagine that the engineering community will still claim you.

Mr. STARK. I ask the gentlewoman if my prepared copy could be made part of the record.

Mrs. BOUQUARD. Without objection, it will be made part of the record following your oral remarks.

Mr. STARK. Thank you.

Mrs. BOUQUARD. You may proceed.

Mr. STARK. I would like to digress for a minute on a couple of points. Unlike cutting weaponry or cutting assistance to the Postal Service, in an efficiently and well-run research project such as the MFTF-B project at Livermore, a reduction in planned funding in these kinds of projects that take many years of advanced planning can have drastic impacts—it is hard to reduce a project by one-third of a physicist or 10 percent of an electronics engineer. It is hard to cut 10 percent out of one research project such as this. In that case the research project ends. If you cut 10 percent, you really cut 100 percent.

I would be perfectly willing to have this committee and have the GAO, who we have asked to look into the progress of magnetic fusion research, tell us whether or not Lawrence Laboratory is being run efficiently, and whether our long-term goal of safe and dependable energy, with a really secure source of fuel might be available 20 years out. I think this committee recognizes and we all recognize that we have got to explore these alternate energy areas to reap any reward in the future.

However, I want to know if these projects are not efficient. If they are not proceeding expeditiously toward their goal, we should examine that. If they are not, I would be the first to come before you and urge you in your oversight capacity to see if they do become efficient and do not waste our money.

I think we will all agree that a project such as MFTF-B is important to our Nation, to its industrial security, perhaps even its national defense. Therefore, we may be in fact penny wise and pound foolish by this latest round of proposed cuts.

I think you are aware that Mr. Edwin Kintner, the former Associate Director of Fusion Energy at the Department of Energy resigned in protest because of cuts in this project.

Mrs. **Bouquard**. I am very well aware of this.

Mr. **Stark**. I think he made a professional and personal commitment to say that our country needs this project.

I think you should consider, if you can, restoring as much as possible to the MFTF-B project. I have suggested off the record that if it is merely a budget question, in my position on the Ways and Means Committee, I would be glad to say we should add an excise tax to the electricity generated by the TVA if we needed to raise money.

Mrs. **Bouquard**. I assure the gentleman that this is highly unlikely.

Mr. **Stark**. There may be other ways, however, that you and I can search out together——

Mrs. **Bouquard**. I am sure you think there are much more advantageous ways.

Mr. **Stark** [continuing]. To find the necessary dollars. I do think this: I have often said—and I say it not in a pejorative sense but in a sense of the witnesses who will follow—our former colleague who heads the OMB has a training in theology. While I have a great respect for the Almighty and our Lord, I am not sure that looking Heavenward is the place to find energy of the future. While I know that our former colleague knows the cost of everything, I am not sure that he knows the value of some of the projects that your committee is funding.

Mrs. **Bouquard**. Your comment is well taken.

Mr. **Stark**. As it sounds, we can $20 million our budget to death, but I am asking that $20 million be restored to the magnetic fusion budget because I think the cuts have been more than just minor. You are going to hear from Dr. Trivelpiece this morning that OMB is continuing to go ahead with the proposed cuts.

If the record will remain open, I would like to submit GAO's report to us on magnetic fusion research. I think that the proposed reductions would do the project far greater harm than just the $20 million cut. I am hoping, in effect, that 5 percent of the total magnetic fusion budget can be restored. I think that it would be more than redundant for me to go ahead and suggest that this committee doesn't realize the importance of the project which they have indeed started.

It was my privilege a month or two ago to have lunch with Congressman George P. Miller, really the father of this committee, on his 91st birthday. One of the projects which he is—probably second only to the space launching—most proud of is the fact that they have taken the lead in creating this kind of research.

I hope, in the spirit of *Columbia* that has lifted off today and is orbiting, that we will not kill this project—lose the shoe for want of a nail, and on down the line.

I thank you for giving me the opportunity to be with you this morning and make my layman's plea for a project that I think needs to continue.

[The prepared statement of Hon. Fortney H. (Pete) Stark follows:]

Testimony of the Honorable Fortney H. (Pete) Stark, Jr. before the Science and Technology Subcommittee on Energy Research and Production

March 23, 1982

LLNL Magnetic Fusion Program

Madame Chairman and members of the Subcommittee, I appreciate the opportunity to present this testimony in support of the restoration of funding for the Magnetic Fusion Test Facility (MFTF-B) in Livermore, California.

I find myself once again in the position of witness before you, espousing the virtues of our nation's magnetic fusion effort--a program which is on the threshold of success due to your past efforts. Congress has clearly and consistently expressed its support, time and again, through fusion funding and the passage of the Magnetic Fusion Engineering Act of 1980.

Every year we find ourselves in this position, trying to save and improve the magnetic fusion energy budget.

I know the distinguished witnesses from the Department of Energy will tell you how well the program is doing, and take credit for the many achievements we have all seen in the past year.

But if everyone is so supportive, why do we so consistently find ourselves in this situation year after year?

I think the answer is that the scientists and engineers who know the importance of these projects to the future of America are gagged by the bookeepers at OMB, who seem to know the price of everything and the value of nothing. The Administration's proposed budget cutbacks would derail and destroy much of the work of the past and make future research efforts even more expensive. Any witnesses who come before you saying the budget for fusion research is adequate are merely repeating what OMB has written for them--and not what they know in their hearts to be necessary or proper for the future of fusion energy research.

Thankfully, this point was made crystal clear by the resignation with honor last year of Dr. Edwin Kintner, former Associate Director of Fusion Energy at the Department of Energy. Dr. Kintner resigned because of the severe, and what he thought were debilitating, cuts to the fusion energy effort. I hope this Committee will be guided by the comments of this resigned official, rather than that of those still under official pressure.

Cost, necessity, and promise all point to the wisdom of an immediate commitment to the engineering phase of the magentic fusion energy program. We know that fusion can become a universally available, environmentally responsible source of limitless energy. We know that the world desperately needs an energy source with these qualities. We know that the cost of developing magnetic fusion will not get any cheaper.

Last year, FY 1982, the entire magnetic fusion budget was $453.8 million. The projections for this year, including growth, construction, and taking into account the critical point at which many programs stand, was $560 million. The President's proposed budget, however, contains only $444.1 million, a nearly $116 million cut! Such an astronomical reduction in funding virtually puts all programs into a holding pattern.

We can not continue with the engineering phases of the programs, and much of the construction and testing will come to a standstill. The big loser in this budget cutting is the MFTF-B project in Livermore, California. The projected budget for MFTF-B was $71 million. Under the Reagan proposal, the funding stands at $46 million, a $25 million cut.

The Associate Director of Magnetic Fusion Energy at Livermore told the Department of Energy that such a cut would set back the timetable for completion of the MFTF-B by at least two and a half years, and "would do major harm to the magnetic fusion program as a whole."

The MFTF-B made outstanding progress in the last year. In February of this year, the giant magnet was tested and performed better than the scientists had hoped. The second magnet to be used in the giant facility is being made now. To severely reduce the MFTF-B budget, as the President has proposed, would not only set the project back significantly, but it would be a catastrophe to the enthusiasm and morale of the scientists connected with the project.

Concessions to our budget restraints can be made. In these times of budgetary imbalance, and severe cuts in other areas, total restoration would be impossible. However, by merely restoring an additional 5%, or a little more than $20 million, to the total budget, we could salvage the programs at Livermore, and elsewhere, and we will be able to move ahead at a reasonable pace into the engineering phase of magnetic fusion development.

I strongly urge the members of the Subcommittee to carefully consider the restoration of at least an additional 5% funding for the magnetic fusion projects across the country. This action will provide a strong, vital and responsible commitment to our nation's energy future.

I would like to add another point. It is very easy at this time to get complacant about energy. Gasoline prices have declined dramatically. There are stations in the Greater Washington area (but unfortunately not in my district) where the price of a gallon of regular leaded gasoline is about $1.10. OPEC appears to be in disarray and it is not clear they can make their production cutbacks stick. Oil supply is up and consumption is way down. It is spring time, and the energy situation looks better--why do we need to keep pressing on the development of alternative, non-polluting sources of energy?

Madame Chairman, I fear that this sense of energy well-being could be very short-lived, and that we must not lose sight of the need for new, clean, safe forms of energy totally under our control.

The situation in the Middle East remains a powder keg. Sadat's assassination proves that. Iran may be winning the war with Iraq, which could lead to a sudden spread of Khomeni-type Islamic fundamentalism which will be virulently anti-U.S. The current disturbances in the West Bank show how fragile the Camp David accord is. Central America is in turmoil and Mexico's huge oil fields are exposed. Every day more of America's oil is drained--and every pound of coal and oil which is burned brings the world atmosphere closer to a point of crisis.

Madame Chairman, there is no reason for complacancy, Just because the President has vetoed the standby allocation authority legislation does not mean that we will not have a crisis. I believe that our energy structure is a house of cards.

To slow up our drive for new, clean, safe sources of energy could be incredibly foolish. Unless we act, it is quite likely that the future historians will look back on this period and wonder why we slept, why we let precious time slip through our fingers.

I urge this Committee--as it has in the past--to recognize the true severity of the energy crisis and to prevent complacancy from derailing our efforts to prove the practicality of fusion energy.

Madame Chairman, I want to thank you for the opportunity to appear before your Subcommittee, and I look forward to working with you and the other members of this Subcommittee in strengthening our energy resources.

Mrs. **Bouquard**. Thank you very much, Pete. We certainly do appreciate your testimony. I agree with you that this is a project which is very vital to our ongoing magnetic fusion program.

The one thing that really struck me is I think it is doing our magnetic fusion program a great injustice. You have to come here because of a project in your district, but really it is just as much in my interest and in the interest of all the people in this room that this project continues. It should not be reduced to "pork barrel status." This program is important for all of us, and I certainly share your concern.

Thank you so much for being with us.

Mr. **Stark**. Thank you very much.

Mrs. **Bouquard**. Now, we welcome Dr. Alvin Trivelpiece who is accompanied by Dr. John Clarke. Welcome, gentlemen, to our subcommittee this morning.

We are certainly looking forward to your testimony. We do have your prepared text so you may proceed as you wish. You may either read your testimony or summarize. Your entire statements will be made a part of the record.

Please proceed, Dr. Trivelpiece.

STATEMENT OF DR. ALVIN W. TRIVELPIECE, DIRECTOR, OFFICE OF ENERGY RESEARCH, U.S. DEPARTMENT OF ENERGY, ACCOMPANIED BY DR. JOHN F. CLARKE, ACTING ASSOCIATE DIRECTOR, OFFICE OF FUSION ENERGY, U.S. DEPARTMENT OF ENERGY; AND D. D. MAYHEW, ACTING DIRECTOR, FINANCIAL MANAGEMENT DIVISION, OFFICE OF ENERGY RESEARCH, U.S. DEPARTMENT OF ENERGY

Dr. **Trivelpiece**. Thank you. I am pleased to be here today to have this opportunity to discuss the fiscal year 1983 budget with you. As you indicated, with your permission, I would like to have our prepared statements submitted for the record.

I am going to make some summary observations; but first I would like to follow up on what you said, indicating that Dr. Clarke is now the Associate Director of the Office of Fusion Energy. I don't need to introduce him to you. He is well known to you already. However, Dr. Clarke is a graduate of MIT, and he worked at the Oak Ridge National Laboratory as a staff scientist in the fusion program. From 1973 to 1977, he was the Director of that program at Oak Ridge. For the past 4 years, he has been the Deputy Associate Director of the Office of Magnetic Fusion Energy. I am certainly very pleased that John has agreed to accept this difficult responsibility for managing this program.

From my own past contacts with some of the members of the subcommittee, I know that most if not all of the members of the committee support the concept of a strong fusion program. I know that you share my belief that this is an important activity for the United States to remain as a leader.

Over the years, the fusion program has made very systematic progress toward its first goal: that of demonstrating that more energy can be released from controlled fusion of light nucleides than is invested in heating and confining of plasma of such nucleides. In fact, the experiments which demonstrate this condition are now scheduled to start at Princeton in late 1985.

The subsequent effort that will be required to translate this laboratory result into a practical energy delivery system is going to require considerable work over the period of many years.

In the meantime, there are going to occur various periods in which there will likely be both a surplus of oil and shortages of oil. There will be years in which the U.S. economy is going to expand and there will be years in which it is going to contract.

There will be pressure to reduce this program when budgets are tight, as they are now, and a desire to expand the program when things are better.

My concern is that the program needs steady even support, not wildly fluctuating support, over an extended period in order to make effective progress.

In this year, we have had to make some adjustments to the program to accommodate the need to control spending. In doing so, I believe that we have still developed a balanced program that will make effective progress in various technical areas in which the program is now engaged.

Your continuing support for this program has been a major factor in achieving the kind of stability which has kept the United States in a leadership position in fusion research throughout the world.

Thank you very much for that support. I would like to now turn to Dr. Clarke and have him discuss some of the details of the program.

[The prepared statement of Dr. Trivelpiece follows:]

Statement of Alvin W. Trivelpiece
Director
Office of Energy Research
Before the Energy Research and
Production Subcommittee of the
House Committee on Science and Technology
March 23, 1982

Madam Chairman and Members of the Subcommittee:

It is a pleasure to appear before this Subcommittee to discuss the Department's FY 1983 budget request for the Magnetic Fusion Energy program. I am accompanied by Dr. John F. Clarke, Acting Associate Director of the Office of Magnetic Fusion Energy. Dr. Clarke will follow my introductory comments with a more detailed discussion of the budget request.

Because of fusion's many attractive features, including a potentially inexhaustible resource base, encouraging environmental and safety aspects, and multiple possible applications, we are working toward an ability to determine its true potential for practical use. Our ultimate goal is to develop environmentally sound and economically competitive fusion systems. To reach that goal, we are supporting research that will build a base of knowledge and understanding on which to make judgments about fusion's practical usefulness.

The program's long-term strategy is to conduct a broad-based program along two concurrent lines. One line is the scientific research effort involving two principal goals: (1) resolution of the remaining technical issues crucial to the production of a burning plasma, and (2) development of reactor concepts that promise reactor characteristics significantly better than current concepts. The other line is the engineering effort aimed at developing experience with the practical problems of creating and maintaining a burning plasma. The synthesis of these two efforts will help us to demonstrate fusion's engineering feasibility and lay the groundwork for a rational assessment of fusion's potential as a practical energy source.

The scientific and engineering feasibility goals are a logical outgrowth of the fusion program's 30 year history. That historical continuum reflects the many changes that have occurred in what has become a complex program. Early researchers were optimistic that fusion could be controlled and turned easily to the production of energy. That optimism was dispelled in the late 1950's when it became clear that substantial scientific research would be needed before scientists would be able to confine plasmas long enough and at high enough densities and temperatures to produce a net energy gain. During the 1970's, systematic progress occurred on a broad front as the result of a carefully planned program. The required temperatures for self-sustaining releases of fusion energy were achieved in several experimental devices and vast improvements in plasma confinement were achieved. We now believe that net energy producing systems are possible.

The term magnetic fusion stems from the fact that the fusion fuel consists of ionized isotopes of the element hydrogen which are contained or "confined" by magnetic fields within a vessel. There are two main classes of experimental magnetic fusion devices, open and closed. Closed systems, of which the tokamaks are the best known, are systems within which the magnetic field lines circle in on themselves in the shape of a doughnut or toroid. The tokamak is the best understood of all magnetic confinement devices and, therefore, the most advanced fusion concept. We plan to finish construction of the Tokamak Fusion Test Reactor this year and fully expect that subsequent experimental operation will lead to the demonstration of scientific feasibility of fusion (i.e., energy breakeven). However, much work remains to perfect the closed magnetic concepts in general to ensure a practical reactor application of these scientific successes.

The mirror concept is an open system where the magnetic field lines are squeezed near the end of a straight section to retard leakage of the fusion fuel. These cylindrical-shaped devices are referred to as mirrors because most of the particles are reflected back rather than escaping from the ends. Significant progress has been made in recent years in improving this device, and today we are establishing the basic reactor feasibility of this class of confinement concepts through the tandem mirror. As in the case of the toroidal systems, a great deal of scientific development needs to be done to evolve a practical reactor concept from these scientific advances. The FY 1983 budget request is designed to continue this fundamental scientific development and to maintain development of core fusion technologies.

In addition to the scientific progress in open and closed magnetic systems, the fusion program has made significant progress in developing basic fusion technology in recent years. Although the emphasis is necessarily on scientific progress, we are not neglecting the development of engineering technology. In parallel with the program's scientific research, we will continue to pursue substantial engineering activities related to the Development and Technology subprogram, the engineering portions of major projects and the Fusion Engineering Device (FED) reference design. Activities related to the FED are aimed at reducing the cost and improving the performance of the reference design as well as evaluating alternatives to the baseline concept. Activities at the industrially-based Design Center hosted by Oak Ridge National Laboratory will be enhanced through an independent corporate level industrial design review. All of these activities will allow us not only to improve the FED design, but to maintain the involvement of industry in the FED design process and increase the involvement of senior managerial level industrial representatives.

Even though the need to meet the President's goal of reduced spending requires that we proceed at a pace slower than that envisioned by the Magnetic Fusion Energy Engineering Act of 1980 (Public Law 96-386), we are continuing a comprehensive scientific and engineering program that will allow us to assess fusion's potential, and continue to work toward our goal of environmentally sound and economically competitive fusion systems.

Madam Chairman, this concludes my testimony. Dr. Clarke will now discuss the program in greater detail and then we will both be pleased to respond to questions.

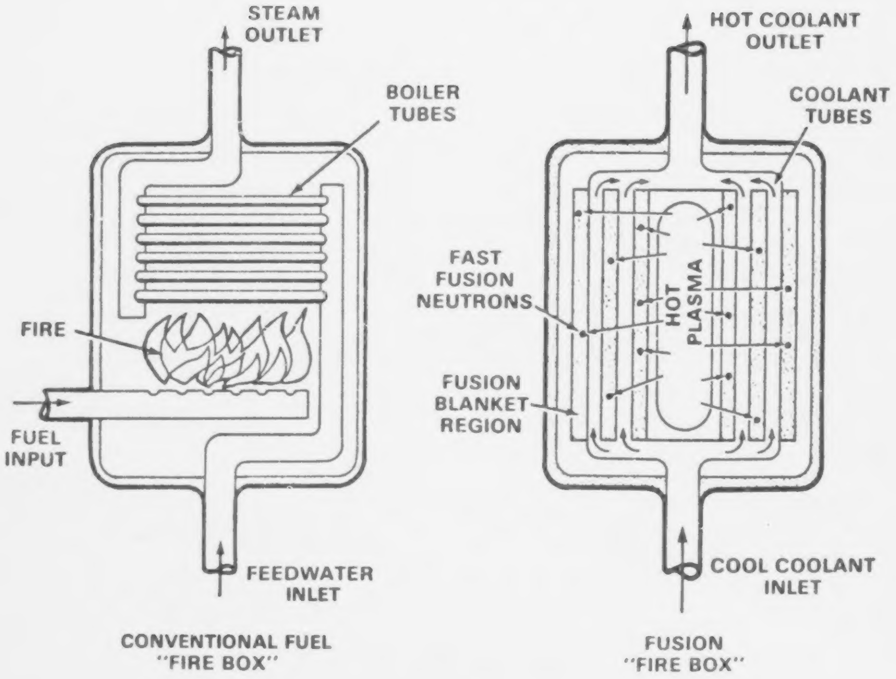
Mrs. BOUQUARD. Please proceed, Dr. Clarke.

Dr. CLARKE. Thank you, Madam Chairman. I would like to use a few viewgraphs to illustrate some of the points that I am going to make.

Mrs. BOUQUARD. Please proceed, Dr. Clarke.

Dr. CLARKE. Thank you.

[Viewgraph 1 shown.]



VIEWGRAPH 1

Dr. CLARKE. The first viewgraph I think will be familiar to the members of the committee. It was first used by, I believe, Dr. Hirsch about 7 years ago. I intend here to establish an analogy between a gas-fired conventional powerplant and the type of fusion powerplant that we are trying to produce with the program.

I will use this analogy throughout the talk to try to give you an instinctive feel for the pieces of the program and why we are running the program the way we are.

The first point to be noticed is that both the conventional gas-fired powerplant and the fusion plant are fed by gas which is injected in from the outside. This is one of the basic things that establishes the fundamental safety of the fusion plant.

The big difference, of course, is that in the conventional powerplant, the heat is produced by oxidation of the electron shells of the atom at temperatures of a few thousand degrees. In the fusion system, the hot plasma is actually producing its energy by burning the nucleus of the atom at temperatures of 100 million degrees, 100,000 times hotter than in the conventional powerplant.

Now, clearly, at these high temperatures, one cannot simply use an ordinary boiler. One has to, as we try to do in the magnetic fusion program, insulate that hot fusion gas or plasma from the walls of the container. We do this by weaving a web of magnetic fields to provide insulation and containment of the high pressure fusion plasma.

In the conventional gas-fired powerplant, the heat which is emitted by the oxidation reaction is transferred to the boiler tubes through the hot gases which come from the flames.

The analogy in the fusion case is that fast neutrons which are emitted by the fusion of the hydrogen nuclei in that plasma, transfer the fusion energy to the structure surrounding the plasma and hence to the coolant fluid which is then used to produce power.

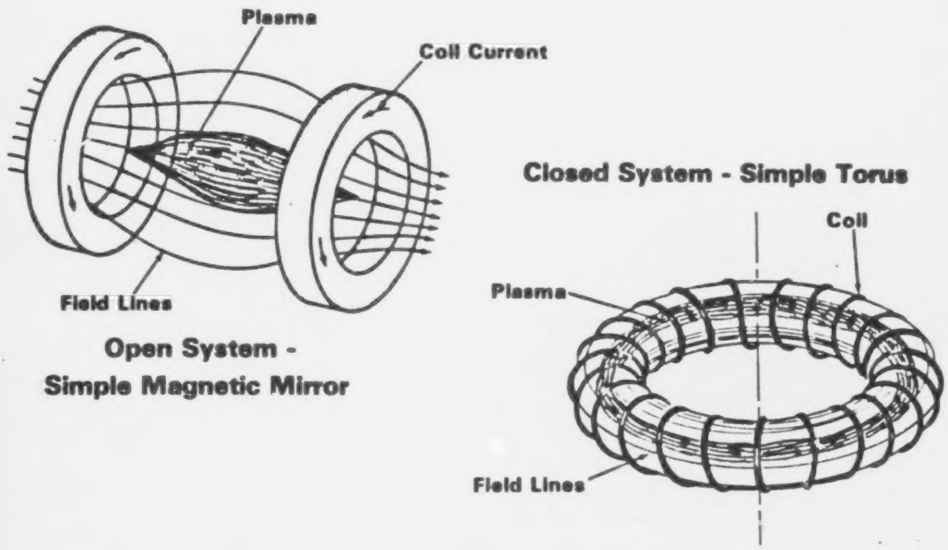
The basic problems that we are trying to address in fusion are the production of that magnetic furnace which provides the insulation for the burning plasma, the provision of heating technology which will allow us to raise the fusion plasma to the necessary temperature of 100 million degrees, and finally, the nuclear engineering aspects of that energy recovery structure outside of the plasma.

Now, in the conventional powerplant, the science, if you will, is associated with that flame. Although we still don't understand all of the processes that go on in ordinary combustion, most of the work in developing a new version of a gas-fired boiler is in the engineering technology.

In fusion, that is not the case. There is an intimate relationship of science and technology in every aspect of the fusion system. It is very difficult to cleanly separate technology from the science in fusion.

[Viewgraph 2 shown.]

THERE ARE TWO BASIC MAGNETIC FIELD CONFIGURATIONS FOR CONFINING PLASMAS



VIEWGRAPH 2

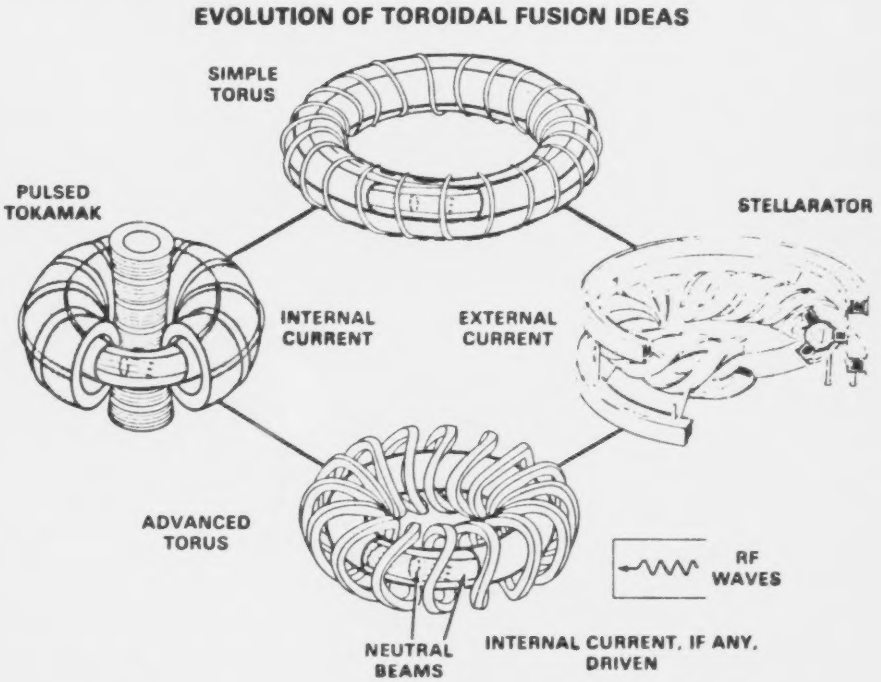
Dr. CLARKE. Now, I would like to go on and describe our progress in developing that magnetic firebox that I referred to.

Although there are only two basic magnetic field configurations that have been invented to contain plasmas, there are a number of variations within each basic type. The one illustrated on the left is the so-called open magnetic system in which the hot fusion plasma is contained between regions of high magnetic fields which are used to reflect the particles which try to escape from the container.

The other basic system is the closed magnetic system illustrated on the right in which the magnetic fields are bent back upon themselves to contain the plasma.

Now, there are so many variants within each basic type of magnetic container that even experts in the field tend to lose sight of the forest for the trees. The forest in this case is the goal of the program which is to develop an economic and practically useful form of magnetic structure to contain the plasma. The trees are the various magnetic concepts that people have invented over the years to try to approach that ideal.

[Viewgraph 3 shown.]



Viewgraph 3

Dr. Clarke. I would like to illustrate this by the next viewgraph which shows the evolution of ideas in one of the basic types of our magnetic structures, the toroidal fusion system.

Shown here is the basic torus which people began to use 30 years ago to approximate a fusion plasma container. It was soon found out that the simple torus system was simply inadequate for adequate insulation of the plasma.

The pulsed tokamak, illustrated on the left there, is a Soviet invention, and it adds to the basic toroidal container a plasma current in the interior of the device which improves the confinement. This tokamak, which is intrinsically pulsed because of the need to induce that current in the plasma, was the device which first produced good confinement.

The device on the right is a device which was invented in the United States. It is called the stellarator. Whereas this device has the potential of being a steadystate plasma container, initial experiments did not yield good confinement results.

In recent years, experiments in Japan, the Soviet Union, and Europe have shown that the stellarator can be made by the use of modern technology into as good a particle container as the tokamak.

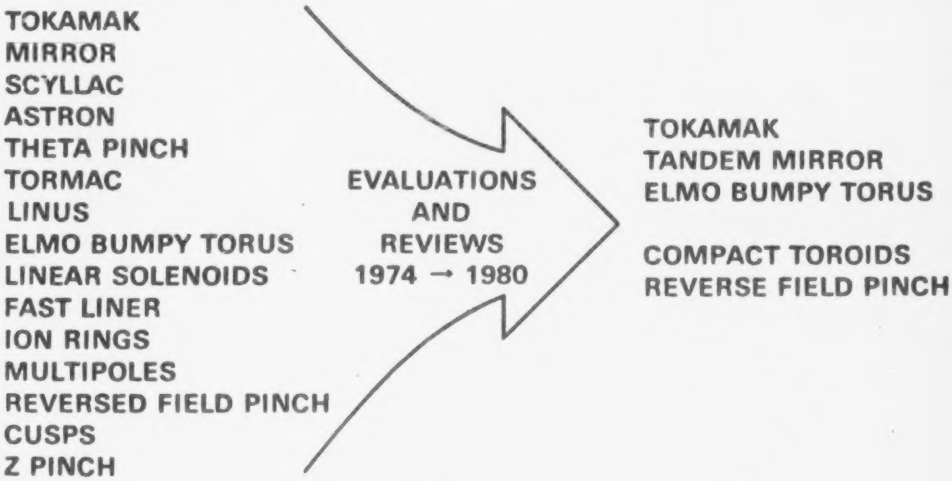
The goal of our program is to try to bypass the disadvantages of the tokamak, namely, its pulsed nature, and the disadvantage of the stellarator, namely, its complicated continuously-wound coils. We hope to evolve from basic scientific investigation of these two concepts an ability to design an optimum fusion plasma container, the advanced forms, which is illustrated on the bottom.

This device can use currents as in the tokamak, driven by radiofrequency power, or it can be operated without a current. The coils are engineering simplifications of the coils in the stellarator which would allow this device to be used more effectively as a reactor type system.

The real progress in the fusion program is not represented by individual parameter achievements on any one of those devices. I believe it is represented by the steady building of knowledge which will allow us some day to design an optimum magnetic system which we can put to practical use.

[Viewgraph shown.]

CONVERGENCE TO MOST PROMISING CONCEPTS



EXPERIMENTS SUPPORTED IN EARLY 1970'S

- TOKAMAK
- MIRROR
- SCYLLAC
- ASTRON
- THETA PINCH
- TORMAC
- LINUS
- ELMO BUMPY TORUS
- LINEAR SOLENOIDS
- FAST LINER
- ION RINGS
- MULTIPOLES
- REVERSED FIELD PINCH
- CUSPS
- Z PINCH

EVALUATIONS AND REVIEWS 1974 → 1980

EXPERIMENTS SUPPORTED IN EARLY 1980'S

- TOKAMAK
- TANDEM MIRROR
- ELMO BUMPY TORUS

- COMPACT TOROIDS
- REVERSE FIELD PINCH

VIEWGRAPH 4

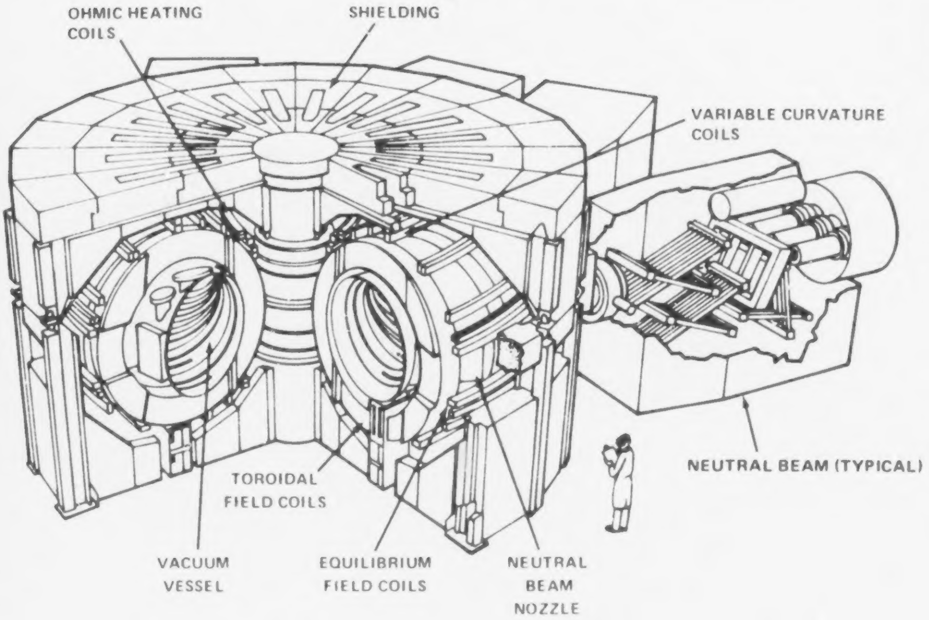
Dr. CLARKE. The program which we have put together over the past few years to approach this goal is shown in this next viewgraph. On the right there are listed five different types of magnetic concepts which were being supported in the early 1970's.

The shorter list on the right shows the list of devices which are being supported in the program today. Over 10 years, we have reduced the number of devices that we support by a factor of 3.

The tokamak listed on the top is the device or the approach which has achieved the highest parameters. The tandem mirror is the most advanced device in the mirror line. The Elmo Bumpy Torus is a device which shares some of the characteristics of both the open- and closed-magnetic systems. In addition, it is used to provide us with experience in steadystate plasma operation today.

The lower two devices, the compact toroids and the reverse-field pinch devices, are closed toroidal magnetic systems which are more exploratory in nature and in fact they are supported by less than 5 percent of our total budget.

[Viewgraph 5 shown.]



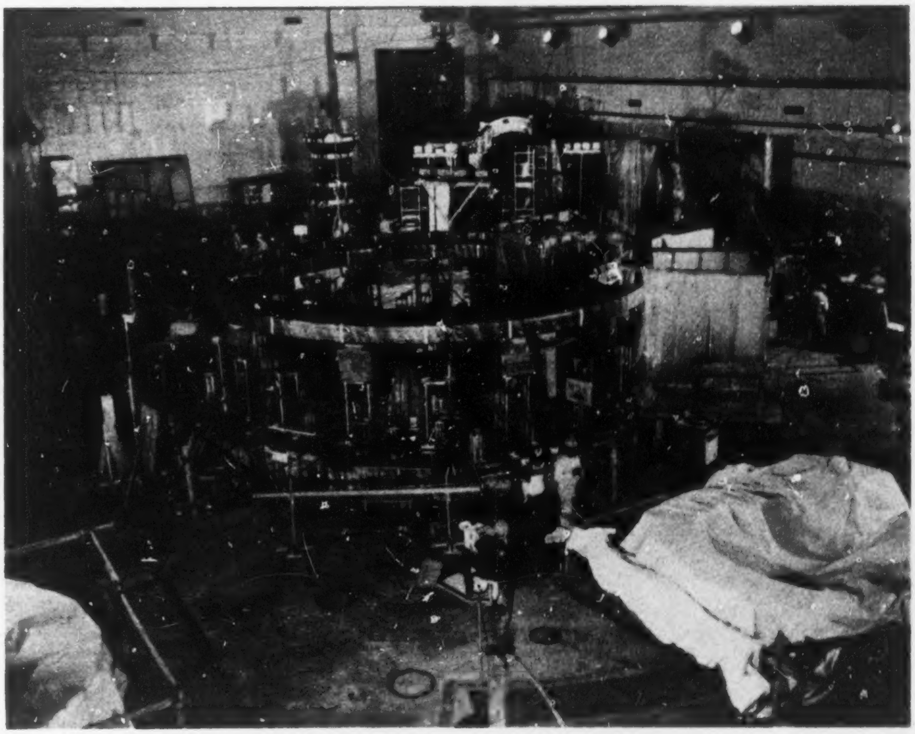
SCHEMATIC DIAGRAM OF TFTR

VIEWGRAPH 5

Dr. CLARKE. I would like to show you some illustrations of the new devices which we are preparing in the fusion program to investigate the scientific principles of these five types of machines.

This is an artist's conception of the TFTR device at Princeton which will, we believe, establish scientific feasibility.

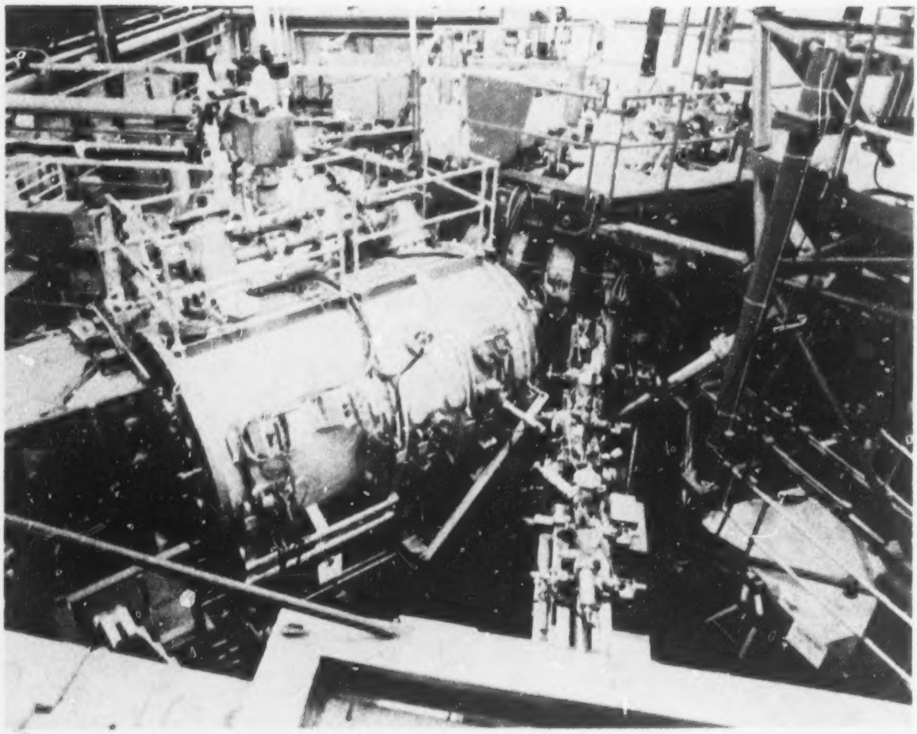
[Viewgraph 6 shown.]



VIEWGRAPH 6

Dr. CLARKE. The next picture shows the actual state of the TFTR at the present time. This is the experimental hall with the large toroidal field coil in the background. You can see a toroidal field coil in the middle and a support structure. All of the major pieces for this machine are onsite, and we believe that the machine will be finished and ready for initial operations by the end of this year.

[Viewgraph 7 shown.]



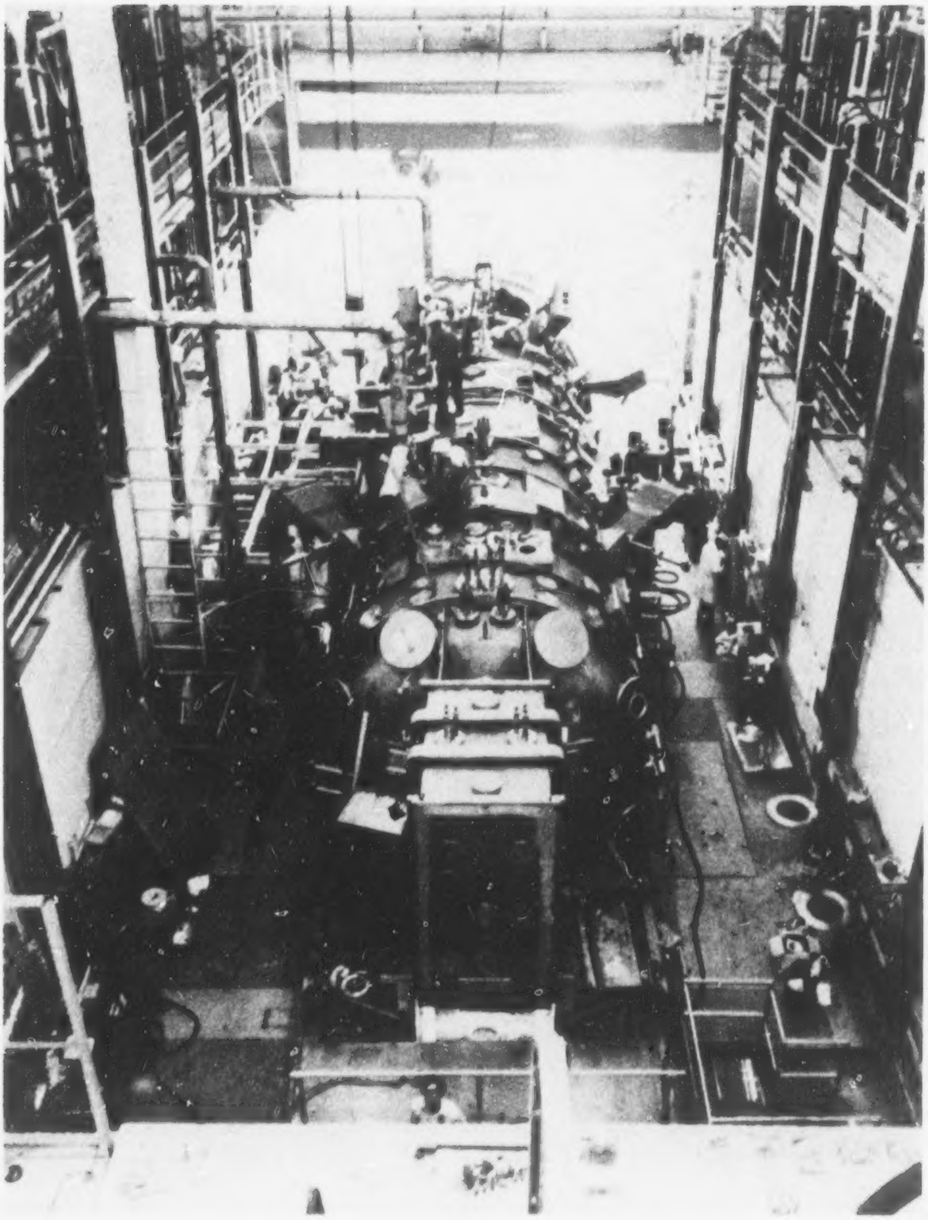
VIEWGRAPH 7

Dr. CLARKE. The next viewgraph shows the Doublet III facility which we completed a number of years ago. What is illustrated here is the large neutral beam injector which has recently been added to this facility to allow us to obtain the very high temperatures, and, more importantly, high-pressure plasma operation.

In the first few weeks of operation with this neutral beam injection, the Doublet III facility has reached record-level plasma betas, betas of over 2 percent, with the injection of only 1 megawatt of the available 7 megawatts.

Next viewgraph, please.

[Viewgraph 8 shown.]

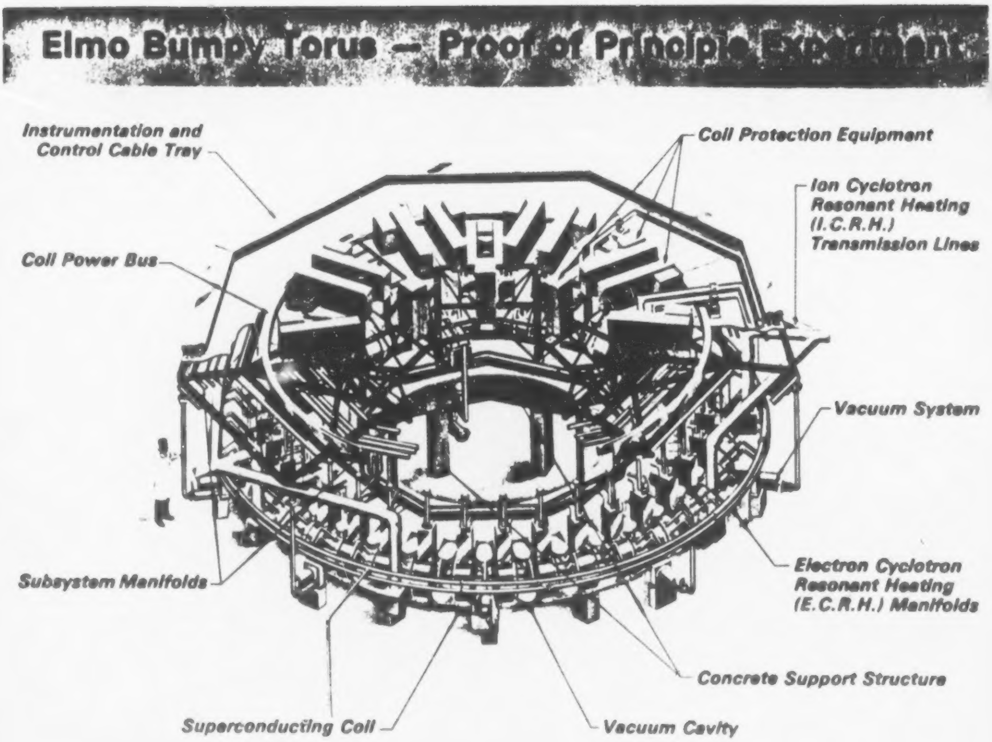


VIEWGRAPH 8

Dr. CLARKE. This is a picture of the new TMX upgrade facility under construction. This facility is now finished and it is beginning operation. This summer we fully expect this machine to investigate the basic principles of the advanced tandem mirror facility. This device is located at Lawrence Livermore Laboratory.

Next viewgraph, please.

[Viewgraph 9 shown.]

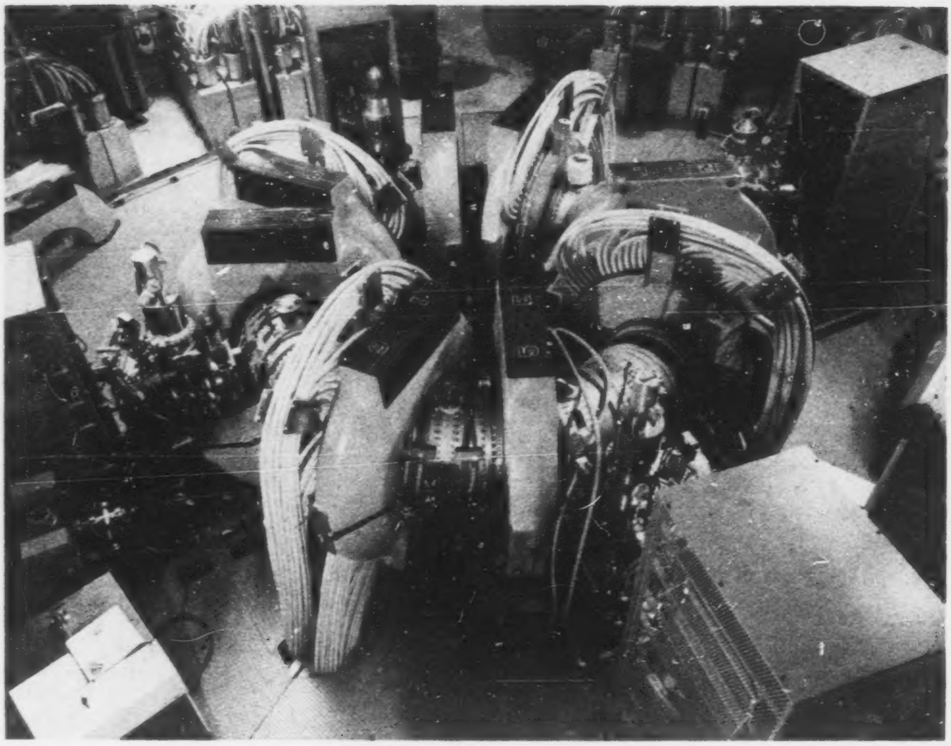

Elmo Bumpy Torus — Proof of Principle Experiment
Instrumentation and Control Cable Tray
Coil Protection Equipment
Ion Cyclotron Resonant Heating (I.C.R.H.) Transmission Lines
Coil Power Bus
Vacuum System
Subsystem Manifolds
Electron Cyclotron Resonant Heating (E.C.R.H.) Manifolds
Concrete Support Structure
Superconducting Coil
Vacuum Cavity

VIEWGRAPH 9

Dr. CLARKE. This is a schematic illustration of the device which I am sure is familar to you. It is the Elmo Bumpy Torus—the EBT-S—which is now in existence at Oak Ridge. The device itself is an old device. The new thing that I want to point out to you is the array of diagnostics and new heating techniques which are being applied to the Elmo Bumpy Torus facility.

We are beginning, through the use of these new diagnostic techniques, to understand a lot more about the physics of this device. Through the application of ion cyclotron and increased electron cyclotron heating, we are also improving the parameters of this device.

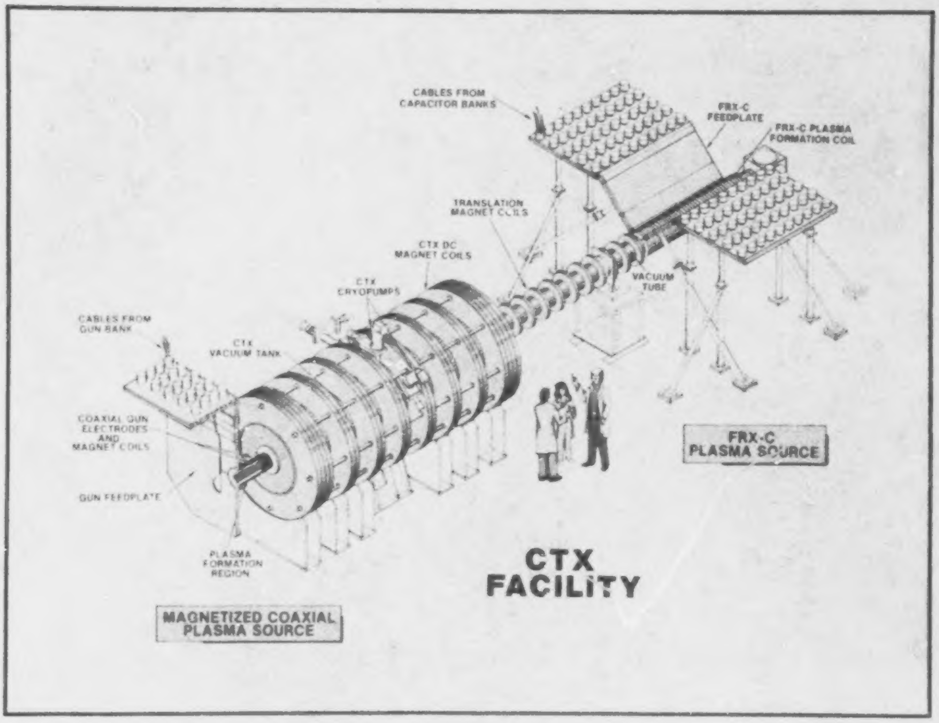
[Viewgraph 10 shown.]



VIEWGRAPH 10

Dr. CLARKE. The next picture is the ZT-40 device which is located at Los Alamos National Laboratory. This is a closed toroidal system of the reversed-field pinch type. The facility was finished over a year ago. It is still not up to full power, but already it has demonstrated a new record in stability for the reversed-field pinches. Through this device, we are getting insight into the characteristics of plasmas which could be used to produce extremely compact, high-powered fusion systems.

[Viewgraph 11 shown.]

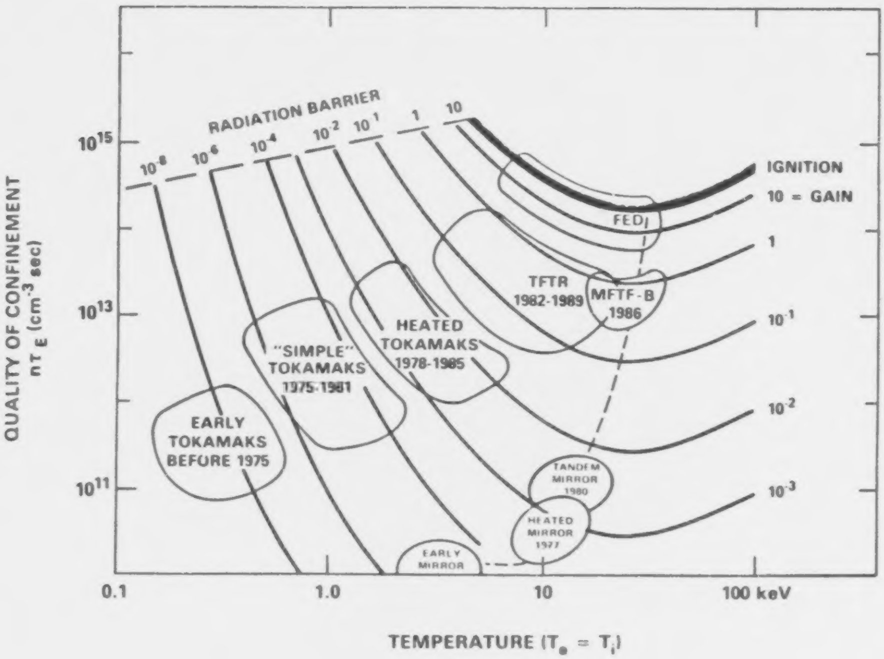


VIEWGRAPH 11

Dr. CLARKE. The final picture is a artist's rendition of a facility which is in existence. It was finished last year. It is called the CTX facility. This is also located at Los Alamos Laboratory. It will be used to test the physical properties of a variety of compact toroidal systems. These are closed magnetic systems with the unique characteristic of having most of the confining magnetic fields produced by currents flowing within the plasma rather than in external coils.

I show you this array of facilities to indicate the the number of new facilities which we have prepared over the past few years and which we must support in order to accomplish our goal of developing the ability to design an effective and efficient magnetic confinement system for practical application.

[Viewgraph 12 shown.]



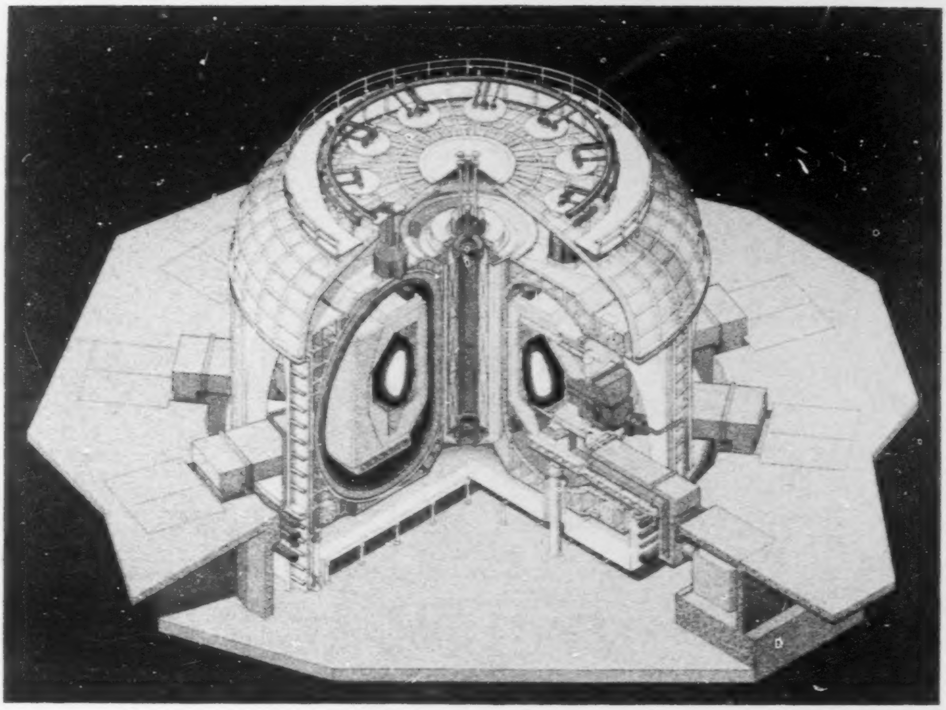
VIEWGRAPH 12

Dr. CLARKE. This is a familiar chart which indicates the overall progress in the program. Shown on the vertical axis is the quality of confinement. Shown on the horizontal axis is the temperature achieved in various systems. The line of rectangular areas going up through the center of the viewgraph represents the close magnetic systems in the form of the most advanced closed system, the tokamak.

Since the early 1970's, we have progressed in both energy confinement time or quality of confinement and temperature to the point that the TFTR which will begin operation later this year is fully expected over the next 3 years of operation to approach and exceed the scientific-feasibility line illustrated by the energy gain-of-unity line on the graph.

The other line of progress illustrated on this viewgraph is the mirror line which is illustrated passing from the early mirrors which had very high temperatures but very poor confinement through the better confined, heated mirrors and finally the recently invented tandem mirrors which are now in operation at the Livermore Laboratory. This line culminates in the MFTF–B facility which we believe would be finished after 1986 and which will advance the open magnetic system to the level of scientific feasibility.

The next step which is illustrated on this slide is the FED. This is a device which will take the engineering technology needed to support the scientific successes represented by the lower areas on that graph and bring these engineering technologies to the level of fusion-reactor development.

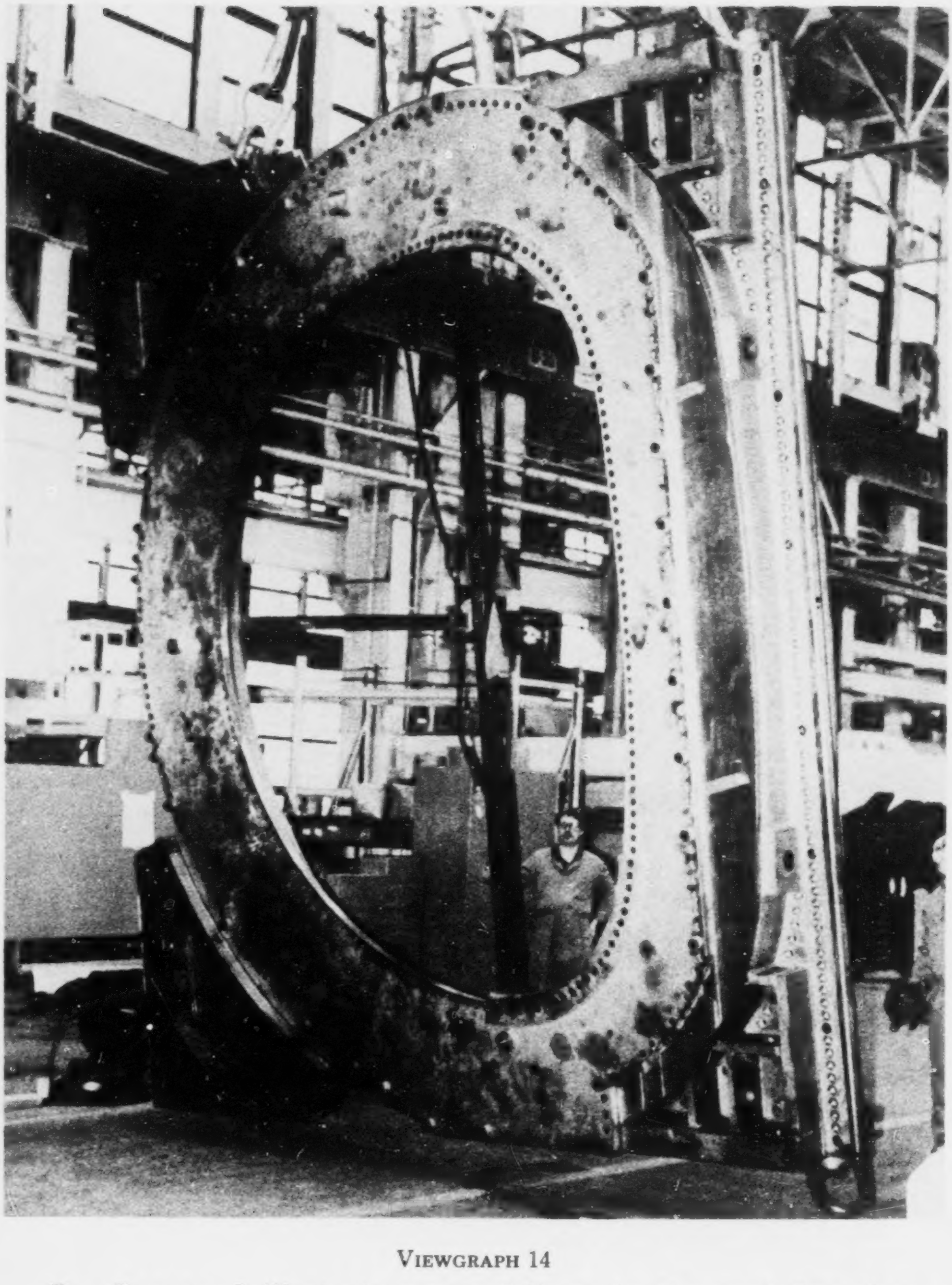


VIEWGRAPH 13

Dr. CLARKE. The next picture shows you an illustration of the basic FED facility, the design of which we have evolved over the last year and a half. This facility has a number of virtues. We believe that it is the first fusion reactor design which is clearly maintainable. We believe that it is a fusion reactor design which could achieve reactor-level power production. However, it is not—and it was not intended to be—an optimized fusion system. Because of the gaps in our present scientific knowledge, we have had to leave room for contingency in the design of this device. Therefore, it is by no means the most efficient or cost-effective fusion system that could be produced. It is simply the best that we can do with our present scientific knowledge.

At present, we are trying to use the new advances in our experimental program to improve the design of this FED and to evolve a most cost-effective means for advancing fusion technology. Even so, in its present design state, the FED is a significant part of the program because it focuses our attention on critical technology problems.

[Viewgraph 14 shown.]

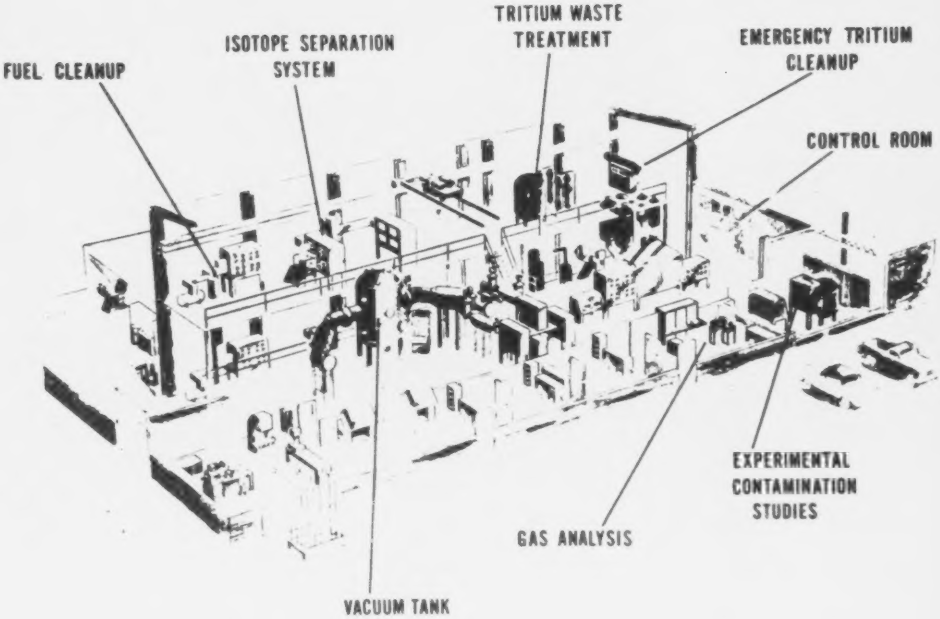


VIEWGRAPH 14

Dr. CLARKE. I illustrate some of these in the next few viewgraphs. This is a picture of one segment of a large superconducting coil being finished at the General Electric facilities in Schenectady. It is one of six coils which are approximately half-FED-size coils which will be assembled into the large coil test facility at Oak Ridge beginning this year.

Next viewgraph, please.

[Viewgraph 15 shown.]


FUEL CLEANUP
ISOTOPE SEPARATION SYSTEM
TRITIUM WASTE TREATMENT
EMERGENCY TRITIUM CLEANUP
CONTROL ROOM
EXPERIMENTAL CONTAMINATION STUDIES
GAS ANALYSIS
VACUUM TANK

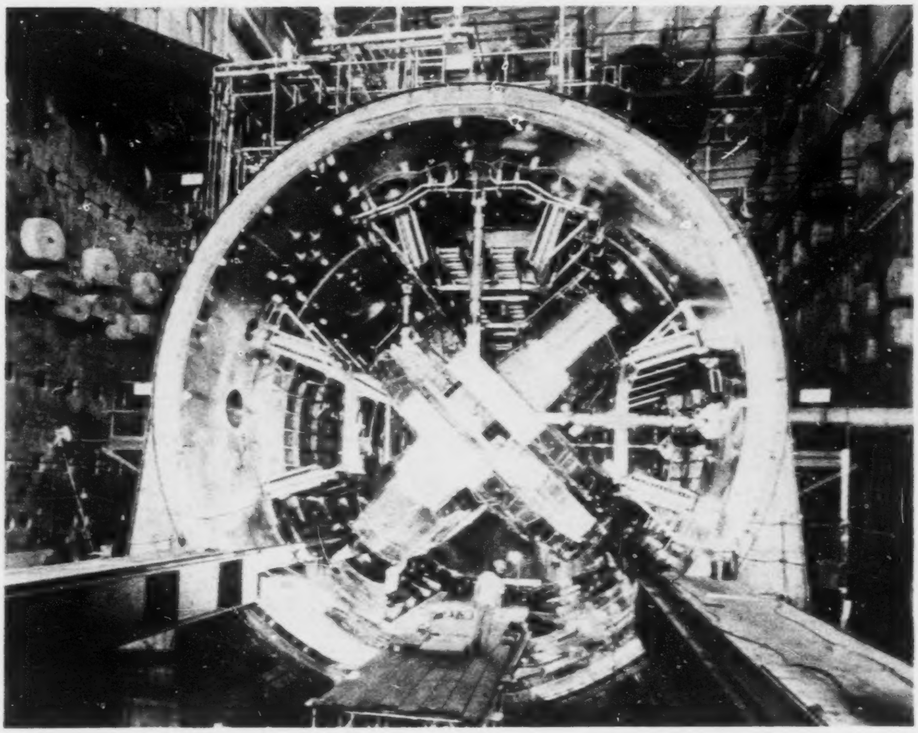
TRITIUM SYSTEMS TEST ASSEMBLY

Viewgraph 15

Dr. Clarke. In addition, I show you an artist's conception of something which is very difficult to photograph. It is the Tritium Systems Test Assembly at Los Alamos. This facility is a full-scale, FED-size, fuel-handling system for the tritium fuel of a reactor. It will allow us to investigate all of the technologies required to handle safely and effectively the radioactive fuel of a fusion reactor. It will also allow us to anticipate any safety problems associated with that fuel system. This facility will also be finished this summer, and it will be operational thereafter.

Next viewgraph, please.

[Viewgraph 16 shown.]

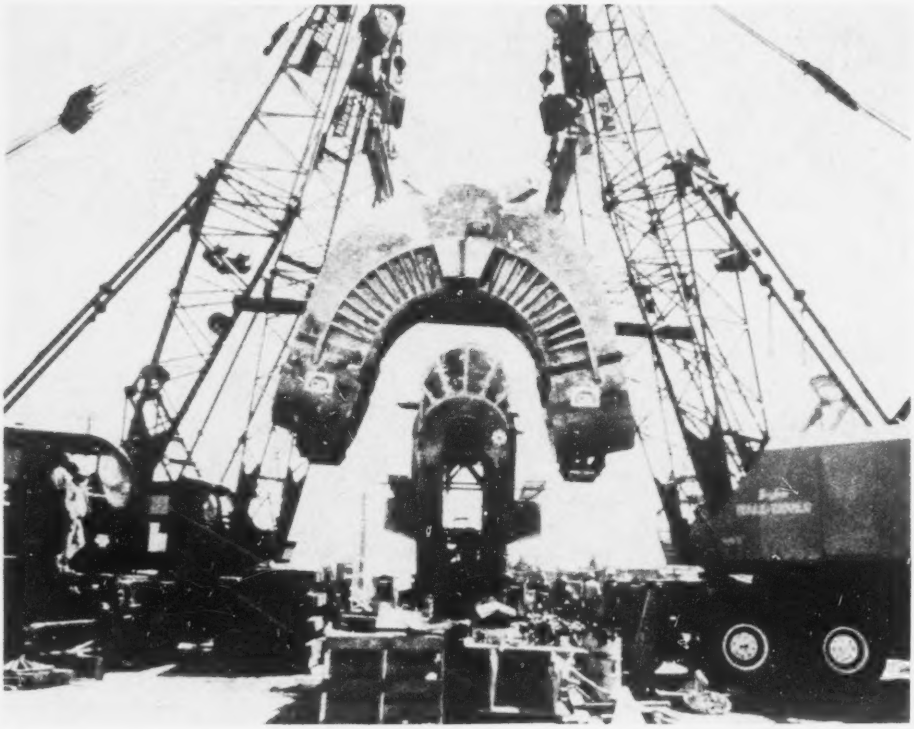


VIEWGRAPH 16

Dr. CLARKE. I would like to emphasize that the engineering technology which we do need to develop in fusion is advanced not only through designs such as the FED and through specific technology-development programs such as the Large Coil Project and the TSTA, but also through the construction of the large facilities which we require to advance our scientific understanding.

This is a viewgraph which illustrates the MFTF-B tandem mirror facility at Livermore.

[Viewgraph 17 shown.]

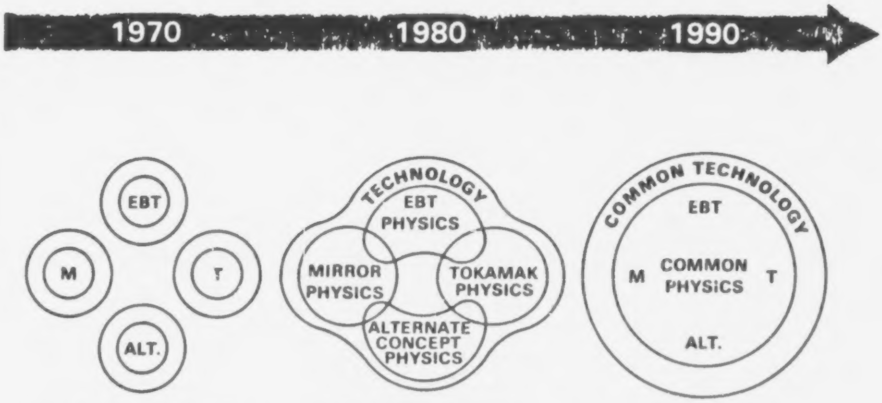


VIEWGRAPH 17

Dr. CLARKE. On the next viewgraph, I would like to show you the world's largest superconducting magnet. It is a 340-ton magnet which was developed to meet the needs of the scientific program envisioned for MFTF-B. This magnet was recently assembled, cooled down, and tested at full magnetic field. It passed the test with flying colors. It marks a major milestone in the advancement of fusion technology. I remind you that this technology was developed for the needs of an existing scientific program, rather than as a pure technology development on its own.

[Viewgraph 18 shown.]

CONVERGENCE OF FUSION SCIENCE AND TECHNOLOGY



SEPARATE APPROACHES WITH SEPARATE TECHNOLOGY

CONVERGING SCIENCE WITH COMMON TECHNOLOGY

GENERIC FUSION REACTOR ENGINEERING BASE

VIEWGRAPH 18

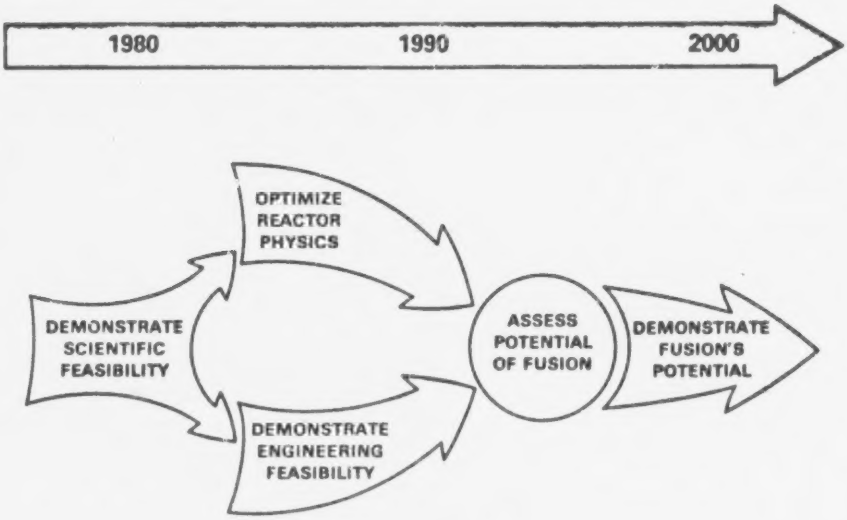
Dr. CLARKE. I would like to summarize the program, past, present, and what we hope to be the program in the future, on this viewgraph.

As I have indicated, 10 years ago we looked on the fusion program as a collection of independent concepts: EBT's, mirrors, tokamak, alternate concepts, each of which was trying to become a reactor system of itself. Over the last 10 years, as we have developed our scientific knowledge, we have found out that there are great overlaps between the physical principles involved with these devices. In fact, I have come to the belief that we will eventually develop a fusion reactor from some combination of the principles which are involved in the number of physical concepts which we are presently investigating.

Another thing which has become very obvious as we have worked through this program is that the technology, which at one time appeared to be unique to each individual approach is overwhelmingly generic. Consequently, we feel that the appropriate way to develop fusion is to develop a common technology base which will support the ultimate practical fusion system that we hope to evolve from our common physics base.

[Viewgraph 19 shown.]

FUSION PROGRAM LOGIC


1980
1990
2000
OPTIMIZE REACTOR PHYSICS
DEMONSTRATE SCIENTIFIC FEASIBILITY
ASSESS POTENTIAL OF FUSION
DEMONSTRATE FUSION'S POTENTIAL
DEMONSTRATE ENGINEERING FEASIBILITY

Viewgraph 19

Dr. Clarke. With that in mind, we have evolved the fusion-program logic which is shown on this viewgraph. Presently I hope we are at the end of the phase which was aimed at the demonstration of scientific feasibilty. We are preparing to enter the next phase of the fusion program.

The next phase of the fusion program has two essential elements. One element is to continue the evolution of our scientific program so that we will eventually be able to design an optimum fusion system that will have practical application. The other essential element is the demonstration of the engineering technology needed to support that scientific concept which is eventually evolved.

This two-pronged program, if followed, we believe will allow us to get to a point in which the industrial concerns that are interested in fusion will be able to assess the practical promise of fusion on a rational objective basis, and we will then be able to proceed toward a practical application of fusion.

With respect to the 1983 budget, we have had to make some difficult choices, as Dr. Trivelpiece has indicated. We have chosen a 1983 budget which we believe will maintain the scientific and technological progress in the existing and newly completed facilities which I have shown you. However, we have had to make some hard choices to meet the overall budget constraints by delaying or deferring major new initiatives in the program.

I think that the program which we have presented to you will maintain the kind of progress that we have had over the last 10 years.

Thank you.

[The prepared statement of Dr. Clarke follows:]

Statement of John F. Clarke
Acting Associate Director for Fusion Energy
Office of Energy Research
Before the Energy Research and
Production Subcommittee of the
House Committee on Science and Technology
March 23, 1982

Madam Chairman and members of the Subcommittee, this is the first opportunity I have had to testify personally before this Subcommittee and I am very pleased to be here today. My purpose is to bring you up to date on fusion program matters as they affect our fiscal year 1983 budget request.

Introduction to Program

Fusion has the potential of becoming a principal energy option for the nation early in the next century. This potential is based on a number of important and attractive features. For example, the fuel reserves for fusion are vast, are readily available to all, and are free from the threat of embargo. The environmental and safety aspects of fusion reactors appear to be reasonable and acceptable; and there are multiple perceived end uses for fusion energy.

Electricity is an obvious use for fusion, but other uses are possible as well. These include breeding fissile material for fission plants, generating very high grade heat which has many industrial applications, and the direct production of synthetic fuels.

The objective of the Magnetic Fusion Energy Program in the Department of Energy is to develop the highest potential of fusion in a way that leads to an economically competitive and socially acceptable energy source for future generations (Viewgraph 1). Because of both the cost and the long term nature of this highly complex scientific and engineering program, it is the Administration's policy that fusion is an appropriate program for federal support (Viewgraph 2). In particular, the National Energy Program III policy document of this Administration recently stated:

> "The Federal Government recognizes a direct responsibility to demonstrate the scientific and engineering feasibility of fusion."

It is not the Department's policy to take the shortest, most expedient, route to fusion power production if that path leads to only another source of electricity. Rather, our policy is to find the best way to develop this new field of science and technology, and to provide the base of scientific understanding and knowledge from which sound judgments can be made on the most economical and practical way to develop this energy source - the energy source of the stars.

Fusion is serving as a technology driver in fields as diverse as superconducting magnets, high power radio frequency tubes and hardware, advanced materials development, and mathematical methods for computers. Fusion makes important contributions in advancing electronics, computer control systems, optics, and many other areas. The impact of this high technology leadership ranges from the marketplace for U.S. goods to the content of engineering programs in our universities.

Principles

Now I would like to take a few minutes to remind you of some of the scientific principles underlying fusion research and development, so that you will be better able to see the essence of our proposed program, which can sometimes be lost in complicated technical descriptions.

In principle, fusion is very simple (Viewgraph 3). Fusion involves the combining of very light nuclei; it is thus basically a nuclear process. There are important fundamental differences between fusion and fission, however. Fusion works by combining the light elements, such as hydrogen, whereas fission works by splitting heavy elements, such as uranium. In both instances, a small amount of mass is lost in the process and converted to energy according to the Einstein equation $E = mc^2$. This energy is then available for use.

The easiest fusion fuel to use is a mixture of the hydrogen isotopes deuterium and tritium. Deuterium is abundantly available in water. A gallon of water contains 1/10 of a teaspoon of heavy water (D_2O), and when this deuterium is combined by fusion with tritium, an amount of energy equal to that released in the combustion of 300 gallons of gasoline is produced. Tritium, the other fuel component, is made from lithium, which is also an abundant element.

In order for the two fuel nuclei to fuse, they have to collide together hard enough to "stick" and form a new nucleus. At low velocity, the positive charge which each nucleus carries will cause them to repel one another and avoid collision by veering away. The desired type of collision requires the high velocities which result from extremely high temperatures. For a mixture of deuterium and tritium, the temperature required is about 60 million degrees. We have already exceeded this temperature in some of our experiments. Since fusion is the energy source of the stars, it is not surprising that fusion temperatures compare to temperatures in stellar interiors. For example, the temperature in the center of the sun is about 20 million degrees. At these great temperatures, fusion reactions become frequent enough that useful energy can be produced. For deuterium-tritium fuel, the end product of fusion is a fast neutron, which carries most of the energy released, and helium, which is like an "ash". This ash, however, is both environmentally benign and a useful commercial product.

The fast neutron escapes from the reaction zone, and is not needed to keep the reaction going. This situation is distinctly different from the chain reaction process required to keep fission going.

At the high temperatures needed for fusion, the fuel atoms have lost their electrons and become a mixture of ions (nuclei) and electrons, known as a plasma. At very high temperatures, all matter exists in a plasma state. Because of its different properties and behavior, plasma has been called the fourth state of matter. Ninety-eight percent of all the matter in the known universe is in the plasma state, collected in the stars and dispersed in interstellar space. It is only in special environments, such as the earth, that plasma is rare, which is why we have little experience with it. Fusion plasma may be envisioned as an electrically conducting, incandescent, fuel gas. Fusion research has driven the development of the science of plasma physics, and an important spinoff from our program has been a great enhancement of our knowledge of the fundamental physical processes operating in the universe.

The very high temperatures required for fusion plasmas mean a good thermal insulation must be found to contain plasmas and confine them from contact with their surroundings. This good confinement is needed to keep the plasma hot, rather than to protect the surroundings. Basically, there are three ways to confine the fusion fuel long enough to burn. These methods are illustrated here (Viewgraph 4). Gravity, the confinement method occurring in stars, is not practical for use on the laboratory scale. Inertial confinement utilizes the high density mass of compressed fuel to keep the fusion reaction going for the required times. This is also the principle used in thermonuclear explosive devices, and inertial confinement is therefore of interest to the nation's defense programs. We can confine plasmas by applying a magnetic field to them, since the electrons and ions in the plasma are charged particles and they tend to stick to the magnetic field lines. Magnetic confinement offers an attractive approach for commercial power development, which is the goal of the magnetic fusion program.

Let me point out that these fundamental energy loss mechanisms are one basis for fusion's inherent safety against runaway accidents. Given some relaxation of the confinement, the plasma will reach its boundaries and cool, extinguishing the fusion process (likely causing some local damage to the first wall it encounters), and stopping further release of fusion heat.

General Program Description

In practice, there is a close analogy between fusion and fossil energy production. Both utilize the same general approach to turn heat into electricity, shown schematically in Viewgraph 5. Both sources utilize the concepts of a firebox and a coolant loop, to transfer heat (Viewgraph 6).

Now let me discuss the magnetic configurations that are under investigation in our program. The magnetic fields which confine the plasma are produced by coils which carry electrical currents. There are two fundamental geometries, or configurations, in which magnetic fields can be made (Viewgraph 7). One is the open configuration. If the field lines are straight, they must be of the order of 50 miles long before sufficiently good confinement is obtained. This situation can be much improved by squeezing the bundle of field lines at two points to create strong magnetic field regions. These regions are called "magnetic mirrors", because most of the particles are reflected from them and confined between them. This works, but not well enough; too much plasma still leaks out through the mirror regions. So the problem is to plug the ends of the magnetic mirror to the point where confinement sufficient to produce net energy is obtained. That is the basic objective of our mirror program, and the most advanced mirror plugging concept being studied is the thermal barrier tandem mirror. Viewgraph 8 shows how the simple mirror configuration evolves into a potential reactor concept by the addition of tandem mirror plugs or through combination into the Elmo Bumpy Torus (EBT) configuration, which shares many features with the second major class of magnetic confinement approaches - the closed system.

If we bend the magnetic field lines into a toroidal shape, the plasma particles will follow the field lines around the torus without being lost. That is the basis of toroidal magnetic confinement. As with the open systems, however, the practical solution is more complicated than that. The simplest toroidal system has very rapid sideways particle losses, due to the curved field lines. To help plug this leak, we can drive a current in the plasma. This approach is called the tokamak, and is the most advanced toroidal concept. Alternatively, we can also drive currents in helical winding around the plasma creating an approach called a stellarator, which has recently made major scientific advances. The next viewgraph (Viewgraph 9) shows the evolution of toroidal confinement thinking from the simple torus to the conventional tokamak, to advanced toroidal systems with steady state current capability or no need for current drive at all.

There are advantages and disadvantages to both types of systems. Open systems lose particles from the ends, but can hold a high plasma pressure. Toroidal systems have no ends, but the plasma pressures are generally lower. Plasma pressure is an important quantity because the power density of a reactor depends on the plasma pressure. There are a number of other less obvious differences between the open and closed systems and among the several variants within each class. The need to understand these scientific differences is not a matter of idle curiosity. They will determine the difference between economically and environmentally acceptable, and non-acceptable, fusion reactors. Our state of understanding is not sufficiently developed at this point to do more than identify these critical differences and lay out a program to evaluate them. A great deal of basic scientific work needs to be finished to ensure the choice of the best fusion system.

About 90% of the fusion budget is used to develop these two approaches through the tokamak and the tandem mirror concepts and to provide their associated generic support. An example of generic support is the reactor materials program. Over the past ten years we have greatly reduced the number of different concepts and configurations we are pursuing (Viewgraph 11). In the early 1970's we studied many different concepts, each supported at a low budget level. We did not understand the connections between these different approaches, and had to await experimental results to see which would work. Today, there is a much deeper understanding of the principles involved, and the wide range of small devices supported in the 1970's is no longer considered necessary. The basic progress in fusion is reflected by the fact that we are converging toward optimized confinement configurations for magnetic fusion reactors.

To improve the basic tokamak and tandem mirror concepts, to broaden our understanding of plasma physics, and to develop fusion, we devote about 10% of our budget to advanced concepts development. Of this effort, the Elmo Bumpy Torus (EBT) is the largest program, receiving about 5% of the budget in fiscal year 1982. The EBT is an approach which evolved in the 1970's out of the U.S. mirror program. It is a machine which combines some of the best features of the tokamak and mirror approaches, and has special features of its own: it is steady state, has relatively modest technology requirements, and may allow a toroidal system with intermediately high values of plasma pressure (beta).

The remaining 5% of our budget is used to pursue research programs in the areas of compact toroids, the reversed field pinch (RFP), and stellarator-type machines, which contain the seeds for future improvements to toroidal confinement systems.

Institutions

Now let me speak for a minute about the institutional structure of our program. There are in the United States six major laboratory participants, as shown by the solid triangles in the figure (Viewgraph 11). There are a number of smaller research sites nationwide, some pictured here. The major laboratories are Livermore, General Atomic, Los Alamos, Oak Ridge, Princeton, and MIT. These six major laboratories are tied together by computer links via satellite to the National MFE Computing Center, located at Livermore. This important network allows all of the major research centers to have access to large, state-of-the-art computers, and permits sharing of computer codes and experimental data. The computer links are being expanded in a phased manner to the other groups.

The major emphasis of each of the major laboratories is shown in the next viewgraph (Viewgraph 12). The Princeton Plasma Physics Laboratory is the largest fusion laboratory in the world and the leading laboratory in this country for tokamak research. Princeton received 28% of our fiscal year 1982 budget. The Oak Ridge National Laboratory conducts not only tokamak research, but also Elmo Bumpy Torus research. Oak Ridge is also heavily involved in technology developments, including superconducting magnets, and the design of the Fusion Engineering Device. Oak Ridge received 20% of the fiscal year 1982 budget. The Lawrence Livermore National Laboratory is the main center for mirror research and it receives 20% of the budget. The General Atomic Company conducts research on the Doublet-III facility, the largest tokamak presently operating in the world. GA spends about 5% of the budget. Los Alamos National Laboratory is the primary center for work on the reversed field pinch (RFP) and compact toroid (CT) concepts; it receives about 5% of the budget. The Massachusetts Institute of Technology works on tokamaks and mirrors, as well as magnet development, and receives about 4% of the budget.

You can see there is a strong university component to the program. Not counting MIT and Princeton, which together account for 32% of our budget, other university programs are funded at over $20 million annually, and have an impact on the program much greater than that number would indicate. The university programs provide a considerable amount of supporting research and diagnostic development essential to progress in our laboratories, are the source of many of the new ideas in the program, and supply the manpower needs, in terms of professional scientists and engineers, that a program of this kind requires.

A great deal of the total fusion budget is expended in U.S. industry, either directly or indirectly. As mentioned, General Atomic operates a major industrial laboratory for the fusion program, which accounts for about 5% of the total budget. The funding passed through to industry via subcontracts with the other laboratories and universities accounts for a much larger percentage. In fiscal year 1982, this industrial support amounted to $190 million, or 42% of the total fusion budget.

Program Strategy

Now let me speak for a moment to the strategy of the program. The program's long term strategy, or logic, involves the conduct of a broad based program along two concurrent lines of investigation, as shown in the next viewgraph (Viewgraph 13). One line is the basic scientific program, which involves two principal goals. The first goal is the resolution of those remaining technical objectives which are crucial to the achievement of a burning plasma. This will be addressed first in TFTR, which will come into operation in fiscal year 1983. The second goal is the development of improved reactor concepts which offer better characteristics in terms of economic, environmental, safety, and reliability factors.

The second line of investigation, which is presently underway, is the engineering effort which is aimed at developing the required technology to take advantage of what we are learning on the physics side and turn it into practical use. The central mechanism for advancing fusion technology to the level required for a Demonstration Plant would be a Fusion Engineering Device (FED), which will permit, for the first time, the production and handling of a significant amount of thermonuclear energy in an environment suitable for both individual component development and testing, and full systems integration tests. The FED role is thus to serve as the major focus for the engineering side of fusion development, with physics development serving as the other major focus in the program.

An assumption of this approach is that fusion engineering systems are, in large part, generic to more than one fusion approach. The commonality of engineering needs is of potentially great benefit to our program. The convergence which is taking place in science and in the evolution of synergistic, improved confinement concepts, is paralleled by a convergence of like kind in fusion technology (Viewgraph 14). Whereas previously we required a variety of separate configurations, each with their own technology, now the program is aiming for the development of a generic fusion reactor engineering base, which will be demonstrated on the FED.

The technical basis which permits a generic approach to fusion engineering is rooted in some basic facts about fusion reactors and how they work (Viewgraph 15). This viewgraph illustrates schematically the components of a fusion reactor. The reactor is shown in cross section, and may be considered either a linear (open) system, or a toroidal (closed) one. If it is closed, the axis of symmetry will be to the right in the figure. The fact that a general reactor schematic can be drawn at all, independent of confinement concept, illustrates the generic aspects of the design. The burning plasma will be confined by a magnetic field perpendicular to the figure, and is isolated from the wall by a vacuum region. Beyond the vacuum wall is a so-called "blanket" region, which has three functions: to absorb neutrons, to breed tritium, and to form the hot side of a heat exchanger. The fusion heat is then available to make steam and spin turbines, or to be tapped for driving chemical reactions or other high temperature industrial processes. Beyond the blanket is insulation to protect the magnets, and then the magnets themselves, which will probably be superconducting.

These features are common to nearly all reactor designs. No matter which plasma system is chosen for confinement, tokamak, mirror, EBT, or some other configuration, the rest of the fusion reactor, which is most of it, will be about the same. The key feature is that the neutrons leave the plasma carrying energy, and deposit that energy outside, remote from the region where the fuel is burned. This feature is unique to fusion. It is not shared by fossil or fission energy systems, and it is one of the things which make generic fusion engineering a practical possibility.

The fusion program strategy means that engineering development costs can be minimized because there will not be a need to have a separate Fusion Engineering Device for each confinement concept in the program. Rather, a common engineering and technology base can be developed for fusion. Our program is intended to develop a solid scientific and technological data base upon which sound decisions can be made on the future directions which fusion development should take (Viewgraph 16). We are aiming for such an assessment in the 1990's.

Next, let me turn to our initial efforts in the enhanced engineering program. During the past year, two significant technical planning activities have been completed which detail these preparations. In one activity, an engineering development plan has been prepared specifying the detailed R&D activities required during the first five years of the engineering feasibility program. In the other activity, a comprehensive planning and design effort was directed at

FED-specific preparations. As a result of this second activity, there is a completed set of volumes that discuss and detail the FED mission and program summary and the baseline design description of major systems and subsystems, including supporting analysis, cost projections, construction schedule and required facilities. The volumes also include a multi-stage, point-by-point test plan for facility use, the physics basis for the design assumptions, and the requisite project-specific research and development activities needed for construction. The FED baseline design was based upon the "conventional" tokamak approach. Taking into account the uncertainty in our present scientific information, the present FED baseline design has room for improvement. However, this design and its associated technology program meets the full definition of engineering feasibility adopted by the Technical Management Board. This Board is a group of outstanding engineers and scientists from our program who have been working closely with the Office of Fusion Energy to develop the technical baselines for the FED. During the next year, we will continue the evolution of the baseline FED design in the light of improved understanding, investigate high leverage physics issues for improving the tokamak, and examine alternative concepts to the conventional tokamak as drivers for the FED. These activities will improve the cost effectiveness of the baseline FED, will allow us to satisfy U.S. commitments to participate in INTOR-related work, and will also allow us to determine if a lower cost alternative path, such as the tandem mirror, can meet the FED requirements.

This program in 1982 and 1983 will involve substantial industrial participation and input. We plan to involve at least eight different firms in these activities, through the Fusion Engineering Design Center and with other subcontracts through the laboratories. Throughout this process the physics and technology data base of the fusion program will continue to be strengthened from experimental and theoretical work in this country and abroad, as we work to improve upon our designs. Viewgraph 17 shows the position which FED has in our plans to move toward practical fusion power.

Technical Progress

This past year has seen continued technical progress in fusion research worldwide. I will touch on only a few of the highlights. Let me begin with toroidal confinement systems. Tokamaks have made substantial progress toward the goal of a steady state toroidal reactor.

In experiments on Alcator C during 1980-1981, there were indications that confinement increased with density as expected, but only up to a point; then increasing the density further resulted in a much slower increase in confinement. There were subtle indications that the plasma in Alcator C was different from Alcator A, where such a "saturation" was not observed; but we did not understand what was limiting confinement in Alcator C. We are now beginning to gain some insights.

A recent set of experiments in Alcator C has indicated that moving the plasma away from the wall, i.e., with a smaller limiter, improves the plasma confinement properties. In fact, plasmas like those in Alcator A have now been produced in Alcator C. Even more interesting is the preliminary indication that confinement improves with the major radius of the plasma. Such a result could lead to tokamak reactors with better access. Efforts are underway now on Alcator C to determine the exact nature of the geometric scaling of energy confinement.

During the past year, a 200 kiloampere current was driven in PLT for one second using lower hybrid waves alone (that is, the ohmic heating transformer was turned off and the plasma sustained by radio frequency driven current only). Important progress has also been made in PLT toward the verification of the FED choice of ion cyclotron range of frequencies (ICRF) heating, by coupling 2.5 MW of power (corresponding to FED radio frequency power densities) with good efficiency.

Additional heating power has been added to several of our large tokamak machines to increase their performance. The first neutral beam line injector is now operating at near its design value on Doublet-III, and the second beam line, which will increase the total heating power to 5 or 6 MW, will be operating by the summer of 1982.

Three tokamaks (ISX-B, PLT, and DIII) are now operating with beta values in excess of 2%, a record high value for tokamaks. For reference, a tokamak plasma of deuterium and tritium will ignite at just over 3% beta at a 50 kG magnetic field, and 5% beta is sufficient for an energy multiplication of 5 in the FED reference design. In 1981, experiments on ISX-B indicated that the plasma beta did not increase linearly with auxiliary heating power at above 2% beta. We took this limitation into account in our FED reference design, and ORNL has been working very hard to identify the limiting factors on this very important parameter. We now believe that the limitation has to do with the value of the plasma current, although there may be other factors as well. Nevertheless, we are encouraged that in the larger, higher current tokamaks, the beta appears to continue to increase as we increase the heating power.

Prospects for higher beta values (perhaps 5%) are good in the coming year on three machines, PLT, PDX, and Doublet-III, with the planned increased heating power. PLT will have 2 MW of neutral beam heating in addition to 3 MW of ICRF heating. PDX will have 6 MW of neutral beam heating, and Doublet-III, 5 MW or more of neutral beam heating (Viewgraphs 18-19).

In the area of mirror confinement systems, there has also been gratifying progress. The Tandem Mirror Experiment-Upgrade (TMX-U) at Lawrence Livermore National Laboratory has been completed within cost and only one month over the original schedule (Viewgraph 20). TMX-U will provide the first experimental tests of two important features of tandem mirror reactors, namely thermal barriers and plasma microstability produced by sloshing ions. Checkout of TMX-U is going very smoothly, and we expect initial results from this machine in a few months.

On the EBT-S bumpy torus at Oak Ridge (Viewgraph 21), the heating power was increased to 200 KW, cw, with a 28 GHz gyrotron developed by Varian Associates. The EBT-S plasma, which is heated by electron cyclotron resonant heating (ECRH), continues to operate steady state and to show the favorable reactor scaling predicted by theory. Record high electron temperatures for a bumpy torus device (over one kilovolt) were measured in EBT-S in 1981, and low power ICRH tests were successfully demonstrated with a clearly extrapolable path for application to EBT-P.

In the Applied Plasma Physics program, modifications to the ZT-40 Reversed Field Pinch device resulted in outstanding physics progress in 1981. Greatly extended pulse times and higher electron temperatures are now routinely obtained. Higher temperatures are expected later this year when the full current is reached. Studies of stellarator configurations have also continued. Theoretical modeling of stability and transport at several laboratories suggests that some stellarator designs may permit a high plasma beta and reduced transport losses, in addition to steady state, disruption-free operation.

The National MFE Computer Center gained a new CRAY-1S computer in September 1981 to augment the saturated CDC-7600 and CRAY-1 computers. This second CRAY machine will be largely devoted to analysis of experimental data obtained from large fusion devices such as PDX and Doublet-III. Also, in January 1982, Oak Ridge, Los Alamos, and General Atomic joined Princeton in having wide band satellite communication links to the large computers at the MFE Computing Center. The satellite links are more reliable and efficient and less costly than the terrestrial lines which they replaced.

In the Development and Technology program, the very successful 28 GHz gyrotron development effort is being followed by a higher frequency development program. In 1982, this program will test a 60 GHz, 200 KW gyrotron at 100 millisecond pulse lengths, and in 1983, cw demonstrations are planned. Also in 1982, the General Electric large superconducting 8T coil will be completed and installed in the Large Coil Test Facility at Oak Ridge. The Japanese coil is complete and undergoing preliminary tests in Japan (Viewgraph 22). The first high fluence irradiation experiments will be completed in the Rotating Target Neutron Source (RTNS-II) at Livermore in 1982, and the upgraded Tritium Systems Test Assembly (TSTA) at Los Alamos will begin FED-scale tritium systems tests (Viewgraph 23).

With regard to the major construction projects, I am pleased to report that significant progress has been made in the past year, and that our project teams have performed well.

The TFTR project is now in the final assembly stage (Viewgraph 24). All major tokamak components are being delivered to Princeton Plasma Physics Laboratory in support of the assembly schedule. Several of the conventional systems are installed and under test. As identified in the fiscal year 1982 Congressional Budget, the project completion milestone with first plasma is December 1982. While potential project completion delays of one to two months beyond December 1982 have been identified, the project team has, with some added risk, been able to compress the required time for critical assembly tasks and reschedule installation and test activities to eliminate these delays. Even if these delays become inevitable, the total estimated cost of the project of $314 million is still considered valid.

The MFTF-B project has passed two very important milestones (Viewgraph 25). The MFTF project was originally begun in 1978 as a single cell minimum-B mirror device, which was upgraded to a tandem mirror device in 1981. The original single mirror project was essentially completed in 1981, on cost and schedule. In a series of tests completed February 4, 1982, the superconducting yin-yang magnet was successfully tested at its full design operating current of 5,775 amperes. The MFTF magnet is the largest superconducting magnet in the world. It weighs 789,000 pounds, stands 25 feet high, and is supported by rods inside the 36 feet diameter, 60 feet long stainless steel vacuum vessel. All related systems, such as cryogenic and control systems, are performing satisfactorily. This test provides a key demonstration that the engineering design for MFTF-B is sound, and increases our confidence in the ability of the fusion program to build and manage large fusion research devices.

The EBT-P project at Oak Ridge (Viewgraph 26) passed its critical physics check point review in August 1981 with a strong recommendation from the review panel to continue. Title I design work is now essentially complete, and we are continuing Title II design.

For the FMIT project at Hanford, we are in the process of completing essential research and development on the radio frequency quadrupole accelerator and intend to finish Title II design this year.

In summary, we are using the present circumstances to the maximum technical advantage of the program. We will modify and re-use existing facilities in as constructive a way as possible, and we will explore the use of other national fusion facilities and foreign scientific progress in a way in which our program has not needed to in the past. With this general introduction, I will now turn to the specifics of our budget request for fiscal year 1983.

FY 1983 Budget

The Magnetic Fusion Energy budget request for FY 1983 is $444.1 million as shown in Figure 27. The fusion budget is organized into five interrelated functional areas that form the basis for a unified and balanced effort in conducting the R&D necessary to develop the highest potential of fusion.

The Confinement Systems and Applied Plasma Physics subprograms, working in conjunction, provide the physics basis for the MFE program. In the near term, the primary driving force in the program is the information derived from the plasma confinement experiments conducted in the Confinement Systems subprogram. These results are reviewed and analyzed by the Applied Plasma Physics (APP) subactivity with the result being development of plasma physics theories and models to explain the experimental results and suggest directions for additional investigations. Based on this information, the APP subactivity initiates experimental work and theoretical investigations of alternate confinement concepts or basic physics problem areas and develops diagnostic instruments for use by the Confinement Systems subprogram.

Based on the program's physics results and projections, the Development and Technology subprogram develops components and systems for use in near and mid-term fusion experiments and develops projects of the most likely nature of the fusion power reactors which will eventually be built. These fusion power projections serve to identify component and system developments which must be undertaken to prepare for eventual commercialization of fusion.

In carrying out the assignments of these three subprograms, needs for major new facilities are identified from time to time. The Planning and Projects subprogram is responsible for constructing these major new facilities.

The Program Direction subprogram provides the funding to cover salaries, benefits, and travel expenses associated with the requirement of staffing the Headquarters Office of Fusion Energy Staff. The FY 1983 budget has been developed to provide the proper balance among these various program activities within the overall funding constraints faced by the Government.

This budget level allows us to continue to support the Administration's policy of developing the highest potential of fusion energy in an environmentally acceptable and economically competitive manner. However, recognizing the need to constrain overall Federal expenditures, it was concluded that some of the previously identified ambitious paths for the development of fusion technology could not be pursued. Instead, the program will follow a slower path of development, with the main thrust in FY 1983 being primarily along scientific lines. This will necessitate the delay, stretch-out, or postponement of several large projects, such as FED, FMIT, EBT-P and MFTF-B, in order to maintain sufficient funding to utilize current generation facilities to address key physics and technology issues in the toroidal and mirror program.

This is illustrated in figures 28 and 29. These tables break down the fusion program between the base program elements (reflected in table 28) and the major projects (table 29). Figure 28 reflects the decision to continue the base physics and technology programs at essentially the FY 1982 effort with slightly larger increases for tokamak and mirror confinement systems to allow full utilization of existing facilities as well as fabrication of new moderate scale devices required to advance the state of physics knowledge in these areas.

Figure 29 shows that the overall funding associated with project support will decrease $37.2 million. TFTR funding shows a slight decrease as the operating level increases and the construction funding decreases. This reflects the transition of the project from the construction phase to the final assembly, check-out and operating phase. The funding request for the Large Coil Test Facility also reflects this same transition as the construction of this project is completed. The development and construction activities on the Mirror Fusion Test Facility-B project are scheduled to continue, however the pace has been reduced from the planned level, resulting in a stretch-out of the project schedule. The project funding for EBT-P decreases as no further construction funds are provided in FY 1983. Design and development activities will be completed on EBT-P in FY 1983 to allow us to be in a position to effectively implement the construction when sufficient funds are available. Construction activities on the FMIT project will cease at the end of FY 1982. Based on the overall stretch-out of the fusion program schedule there is a reduced urgency to provide for this materials test facility at this time.

Figure 30 shows that the FY 1983 budget request of $444.1 represents a decrease of $9.7 million from the FY 1982 level. This change consists of an increase of $65.8 million to the operating program off-set by decreases of $2.5 million in capital equipment and $73.1 million in construction funding. This request has been judged to be the minimum funding level required to carry out a meaningful scientific program without terminating options prematurely. This will allow research to continue in a logical and efficient manner in order to provide a sufficient data base of information to be generated to allow the development of fusion technology to move forward with a minimum amount of risk in the future. It is our judgment that this budget provides the proper balance of funding between various program elements and that reductions below this level would require the development of an alternate strategy for achieving the programs objectives. The following is a detailed description of the proposed program for FY 1983. All of the supported described are aimed at this goal either through improved performance, reduced costs, more effective options or better understanding of subsequent research decisions.

Applied Plasma Physics

Applied Plasma Physics provides the physics understanding necessary for interpreting present experiments and scaling to future generation devices as well as providing the necessary calculations for design of components for future fusion devices.

Efforts in FY 1983 will continue in four subactivity areas. In the experimental plasma research area, studies will develop the data base in atomic and molecular physics required for such things as impurity control and ion source physics, and will explore promising new techniques of plasma heating and diagnostic methods. The fusion theory subactivity will develop and apply models and mathematical techniques to describe the behavior of magnetically confined plasmas and interpret the results obtained in existing confinement devices. The MFE Computer Network subactivity will provide the integrated computing resources to all parts of the magnetic fusion program. The final subactivity is the advanced fusion concepts subactivity which carries out investigations of alternate reactor concepts that have potential advantages over the more conventional tokamak and mirror systems. Figure 31 shows that the FY 1983 budget request for the Applied Plasma Physics subprogram of $77.3 million represents an increase $3.7 million over the FY 1982 level of $73.6 million. This increase will support R&D efforts for Advanced Fusion Concepts (+$1.6 million), Experimental Research (+$1.6 million), Fusion Theory (+$1.4 million) and Computer Network (+$1.3 million). These increases are partially off-set by a reduction in capital equipment (-$2.2 million).

In FY 1983, the Advanced Fusion Concepts budget will continue to support the experimental tests of fusion concepts which are alternatives to mirrors and tokamaks. This area of research will contribute to the major program objective of exploring physics options that might lead to more optimized reactor approaches.

The budget request of $17.1 million will be used primarily to complete fabrication of the S-1 Spheromak in order to provide a facility to test the equilibrium and stability of the spheromak configuration. Operation of the ZT-40 reversed field pinch device will continue to extend performance to maximum conditions, and measurement of energy confinement time. Two new compact toroidals will operate to produce experimental results necessary to allow an optimized reactor version to be analyzed. An assessment of the alternate fusion fuels will be completed in FY 1983.

The Experimental Research subactivity will continue to provide data on plasma properties, atomic physics, and new diagnostic techniques for support of confinement experiments. The budget request of $17.1 million will provide for continuation of FY 1982 efforts that are productive and relevant and to expand the TEXT operation with the addition of an ion beam diagnostic system.

The Fusion Theory subactivity budget request of $22.8 million will allow many key tokamak and mirror theoretical topics to be addressed along with maintaining a level of modest support for EBT and other alternate concepts.

The National MFE Computer Network provides large and medium scale scientific computers for the entire magnetic fusion program. The requested funding level of $14.5 million provides for continuation of the FY 1982 level of effort at the computer center at LLNL and the six user service centers at GA, LLNL, LASNL, MIT, ORNL, and PPPL.

Capital equipment funding in support of the planned operating program, of $4.0 million is required.

Confinement Systems

The activities under this subprogram are aimed at demonstrating and refining methods of heating and containing high temperature plasmas in toroidal and mirror systems. Support of these two primary approaches will continue in FY 1983.

Toroidal devices are operated to investigate specific physics issues such as high magnetic fields, neutral beam and radio frequency heating, size scaling, and pellet injection fueling. The common goal of all experiments is to understand how basic plasma parameters scale with increases in various machine characteristics.

The Alcator-C emphasizes the study of high density plasmas produced by high power density ohmic heating made possible by high magnetic fields. The Doublet experiment stresses the use of non-circular plasma cross-sections to obtain the efficient use of magnetic fields and large plasma currents. The PDX and ISX-B emphasize cross-section shaping, high-power neutral beam heating and divertor control of impurities. The PLT device stresses transport and scaling, and heating.

Figure 32 indicates that Toroidal Confinement Systems budget request for FY 1983 is $153.3 million; an increase of $50.5 over the FY 1982 level of $102.8 million. This increase allows us to restore the level of experimental operation in current toroidal devices to the FY 1981 level of effort (+$7.9 million), to complete preparation for operation and to initiate operation on the TFTR device (+$33.0 million), to initiate fabrications up-grade and modify two current devices (+$7.0 million), and to provide the appropriate level of capital equipment funding to support planned operations (+$2.6 million).

The request of $58.5 million for Research Operations provides for continued support of experiments on ISX-B, PLT/PDX, Doublet III and Alcator-C. ISX-B will investigate impurity controls utilizing mechanical limiters and bundle divertors, and develop a steady-state current drive with electron cyclotron heating. PLT/PDX will investigate high beta and impurity control issues and continue RF heating and current drive experiments. Doublet III will operate full time to continue studies of cross-sectional plasma shapes at reactor-like conditions with higher neutral beam power. Alcator C will be operating near its design parameters using 4MW of lower hybrid wave power for auxiliary heating.

The FY 1983 budget includes $69.0 million to complete preparation and initiate operation of TFTR. This major new device will allow scaling experiments to be conducted to demonstrate energy breakeven for the first time in a fusion device. The budget request includes $23.3 million for facility operations, $12.5 million for technical support, $13.2 million for experimental operations,

$13.0 million for diagnostics and $7.0 million for the CICADA control and instrumentation system. FY 1983 represents a year of transition for the TFTR project from the construction and assembly phase to the operational phase. Therefore, while the FY 1983 budget reflects a significant increase in operating funds, this is off-set by a decrease in construction funding under the Planning and Projects subprogram resulting in essentially no change in the total expenditures for TFTR.

The funding request of $10.2 million for Major Device Fabrications supports the continued fabrication of the electron cyclotron heating system on Doublet III and initiation of two new projects including a new large d-shaped vacuum vessel for Doublet III device and an Advanced Toroidal Facility to replace the ISX-B facility. The new Doublet III vessel will provide a facility for testing FED-relevant components and advanced toroidal applications, such as current drive with large ICRF waveguide antennas. The Advanced Toroidal Facility (ATF-1), at ORNL, will provide the U.S. with its first major stellarator device and will test beta limits and collisionless transport in a current free stellarator configuration. Recent developments in Japan and West Germany and worldwide theoretical work have increased confidence in the stellarator as a potential alternative to tokamaks, as a steady-state toroidal reactor.

The capital equipment request $15.6 million includes $8.0 million to support equipment needs for TFTR with the remaining $7.6 million to support on-going base program activities in the toroidal confinement area.

The research facilities in the magnetic mirror confinement program are designed to address the physics question of plasma heating to thermonuclear conditions, scaling of confinement times and improvement in fusion energy yield in both open and closed mirror systems. In open systems, the Tandem Mirror Experiment-Upgrade and the Phaedous are the primary devices for testing the tandem mirror concept. The Symmetric Tandem Mirror Experiment is designed to test an advanced concept of the tandem mirror approach using hot electron plasmas. In the closed mirror systems, the Elmo Bumpy Torus device is addressing the closed mirror concept by conducting scaling experiments relative to confinement, stability, and heating issues.

Figure 6 indicates that Mirror Confinement Systems budget request for FY 1983 is $49.5 million; a decrease of $3.8 million from the FY 1982 level of $53.3 million. This level allows us to continue to pursue research on tandem mirror and bumpy torus mirror concepts on several devices including TMX-U, Phaedrus, STM, MMX, and EBT-S. Fabrication of the TARA axisymmetric tandem mirror will continue. R&D in support of detailed design on the Elmo Bumpy Torus Proof-of-Principle project will continue to essentially allow completion of detailed design on this project.

The request of $32.7 million for Research Operations will provide for the first full year of operation on the TMX-U device to investigate sloshing ion stabilization, thermal barriers, electron cyclotron heating and radial plasma transport studies. Phaedous will be operated to study R.F. applications in tandem mirrors. Other smaller mirror devices receiving funding support include the Symmetric Tandem Mirror and the Multiple Mirror. Research operations will also continue on EBT-S to strengthen the bumpy torus data base in the area of independent direct ion heating and studies of stable operating regimes. R&D in support of the EBT-P design effort will continue at a level of $4.0 million. This will allow design to be essentially completed so that construction can be implemented effectively when sufficient funds are available.

Capital equipment support will be provided to support the on-going base mirror program efforts.

The FY 1983 budget does not include a request for any further construction funding on the Elmo Bumpy Torus Proof-of-Principle project at ORNL. The current plan is to utilize FY 1982 project funding ($17.4 million) along with $4.0 million of FY 1983 R&D funds to essentially complete the detailed design of the project. This will allow us to be a position to effectively implement construction of this project when sufficient funds are available.

Development and Technology

The goal of this subprogram is to develop the engineering and technological base needed to support the demonstration of engineering feasibility of magnetic fusion. In addition, technical support is provided for current fusion experiments.

The budget request for FY 1983 of $84.0 million provides for an increase of $3.6 million over the FY 1982 request of $80.4 million. This will provide for continuation of systems engineering and component and materials development. Figure 34 indicates that $74.3 million is allocated to six operating categories and $9.7 million is for capital equipment.

The operating request provides for essentially maintaining the FY 1982 level of effort in the six different operating categories. The request of $16.7 million for magnetic systems provides for continuing engineering design and component development of large superconducting magnets and energy storage systems. Construction of the Large Coil Test Facility will be completed and initial operations will be supported during FY 1983. The request of $19.7 million for Plasma Engineering provides for continued design and component development of plasma heating systems, plasma fueling, direct energy convertors, and vacuum systems. The increase will be essentially used to increase efforts on developing long pulse steady-state beams, gyrotrons, negative ion beams, and ion cyclotron radio frequency heating techniques. The Fusion Reactor Materials category will continue to work on developing the high performance materials required to permit the economic generation of energy from the fusion process. A total of $15.7 million is requested for this category in FY 1983. A major aspect of the program will be to evaluate the damage phenomena that occurs in the fusion environment to establish the basis for the engineering requirements for the design of fusion reactors. The Fusion Systems Engineering category has primary responsibility for developing the technology for tritium handling, blanket, shielding and other systems for fusion reactors, as well as conceptual reactor design studies, system studies of economics and technical feasibility, plasma system analysis and plant system design and test. These studies will allow us to develop the technology data base for predicting fusion technology requirements. The FY 1983 budget request for this category of $17.1 million represents an increase of $6.0 million over the FY 1982 level. However, $5.0 million of this increase is for support of activities which were previously budgeted under the Center for Magnetic Fusion Energy category. Thus the actual increase in this category is $1.0 million. In FY 1983 conceptual design and feasibility assessments will continue at the FY 1982 level of effort. Efforts on blanket and shield engineering will continue to provide supporting technology for the design, analysis and verification of first wall blanket and shield systems for fusion reactors. Operation of the Tritium System Test Assembly will be initiated to study tritium clean-up and control technology. As mentioned previously $5.0 million will be provided for CMFE related activities to extend and refine the FED reference case design based on the latest results from the experimental program. This will allow us to be in a position to initiate detailed design on the FED expeditiously and efficiently when the budget situation allows it. The budget request for the Environment and Safety category of $2.9 million provides for continuation of environmental analysis studies and fusion reactor safety research. The Fusion Energy Application category will continue to examine potential fusion applications other than central station electric power at a level of $2.2 million.

The request for capital equipment of $9.7 million represents a decrease of $3.0 million from the FY 1982 level. This is primarily associated with completion of LCTF construction.

Center for Magnetic Fusion Energy (CMFE)

Figure 35 reflects the fact that no funding is budgeted under this subprogram in FY 1983. The CMFE subprogram was presented as a separate budget element in FY 1982 when an acceleration and expansion of efforts in this area was anticipated. The amount of funding has now been reduced to a level at which a separate budget element is not justified and thus has been returned to the Development and Technology subprogram in which it originated.

Planning and Projects

This subprogram will continue to provide direction and technical overview of major construction projects and development programs to support these projects. In FY 1983 this subprogram includes the Mirror Fusion Test Facility-B project at LLNL and development and fabrication tasks associated with TFTR flexibility modifications.

MFTF-B is a thermal barrier tandem mirror device which will be the largest experimental tandem mirror facility in the world, capable of investigating plasma parameters 100 times beyond those of current experiments. Objectives of this facility include investigating confinement conditions under reactor related conditions, exploring confinement scaling in a tandem mirror configuration and providing technological advances in the areas of heating systems, vacuum vessel pumping systems, superconducting magnets, computer control and operation of large plasma facilities.

The TFTR flexibility modifications consist of hardware modifications and additions which will provide a significant enhancement to the plasma performance parameters and operate in physics regime in which self heating of the plasma occurs as a result of the burning of D-T fuel. The flexibility modifications will continue, with $20.0 million requested in FY 1983 for fabrication of vessel armor plating to withstand higher heat loads, fabrication of vessel surface pumping hardware, development, fabrication and installation of longer neutral beam pulse length capability and power supplies for higher vertical magnetic fields.

Figure 36 shows that the FY 1983 budget request for MFTF-B of $46.0 million consists of $6.0 million of operating funds and $40.0 million of construction funds. The operating request consists of $1.6 million for development activities, $3.4 million for auxiliary component development, and $1.0 million for facility preparation. The construction funding request of $40.0 million provides for continuation of design and fabrication of superconducting magnets, vacuum vessels, cryogenic system and power supplies.

The MFTF-B request represents a $25.0 million reduction below previous planned funding levels resulting in a delay in completion from the fourth quarter of FY 1985 to the third quarter of FY 1986. This completion date is contingent on approval of FY 1983 and FY 1984 budgets. Total project cost will increase $33.6 million from $350.4 million to $384.0 million.

In addition, we are recommending that construction be deferred on the Fusion Material Irradiation Test Facility until sufficient funds are available to pursue the project efficiently. Since funding stringencies have stretched out the fusion program schedule, in particular the engineering effort, there has resulted a reduced urgency to test materials. However, we are initiating discussions about future financial participation in FMIT with Japanese and European program managers.

Figure 36 also shows that the Planning and Projects subprogram includes $4.0 million for continuing support of general purpose capital equipment requirements at ORNL and $6.0 for general plant project requirements at ORNL, PPPL, LLNL and LASNL.

Program Direction

The budget request includes $4.0 million for salaries, benefits and other expenses associated with 71 full time equivalents to administer the program. No increase in staffing level is requested over the FY 1982 level.

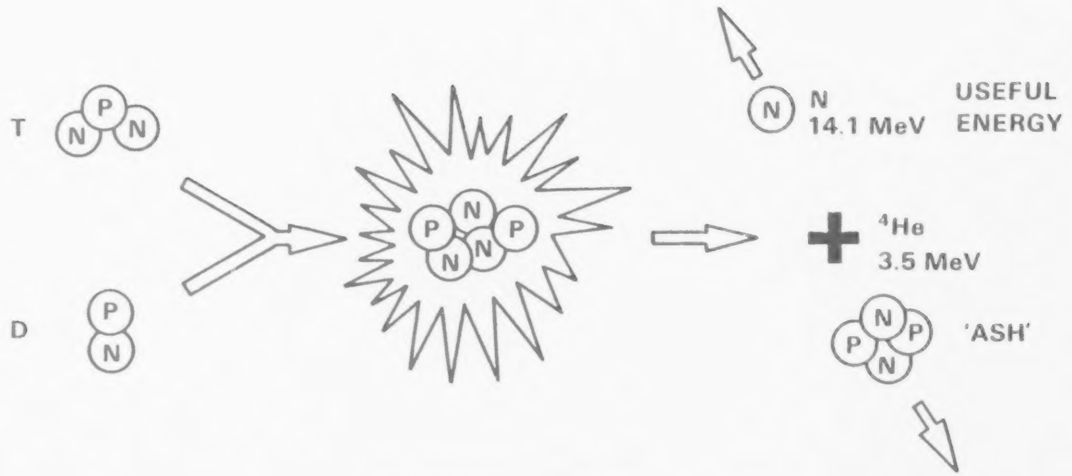
THE DEPARTMENT OF ENERGY'S FUSION POLICY CAN BE STATED IN A FEW WORDS

TO DEVELOP FUSION ENERGY IN AN ENVIRONMENTALLY ACCEPTABLE AND ECONOMICALLY COMPETITIVE MANNER

THE PRESIDENT HAS CLEARLY ESTABLISHED THE FEDERAL ROLE IN ENERGY IN THE NATIONAL ENERGY PLAN

- "THERE IS AN APPROPRIATE FEDERAL ROLE IN CERTAIN LONG TERM RESEARCH & DEVELOPMENT."
- "THE GOAL OF LONG TERM R&D IS TO DEVELOP PROMISING TECHNOLOGICAL INNOVATIONS TO THE POINT WHERE PRIVATE ENTERPRISE CAN REASONABLY ASSESS THEIR RISKS."
- "THE FEDERAL GOVERNMENT RECOGNIZES A DIRECT RESPONSIBILITY TO DEMONSTRATE THE SCIENTIFIC AND ENGINEERING FEASIBILITY OF FUSION."

THE FUSION PROCESS



FUEL

- MANAGEMENT
- REFUELING

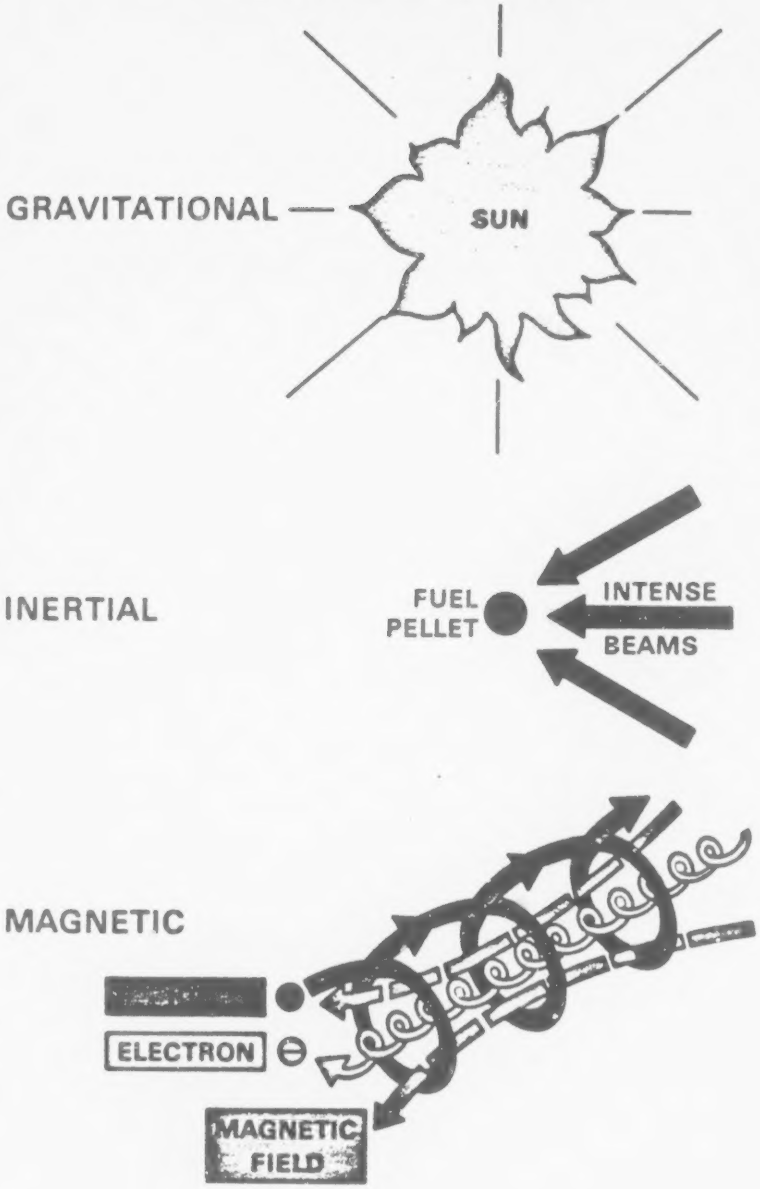
REACTION CONDITIONS (DENSITY, TEMPERATURE, TIME)

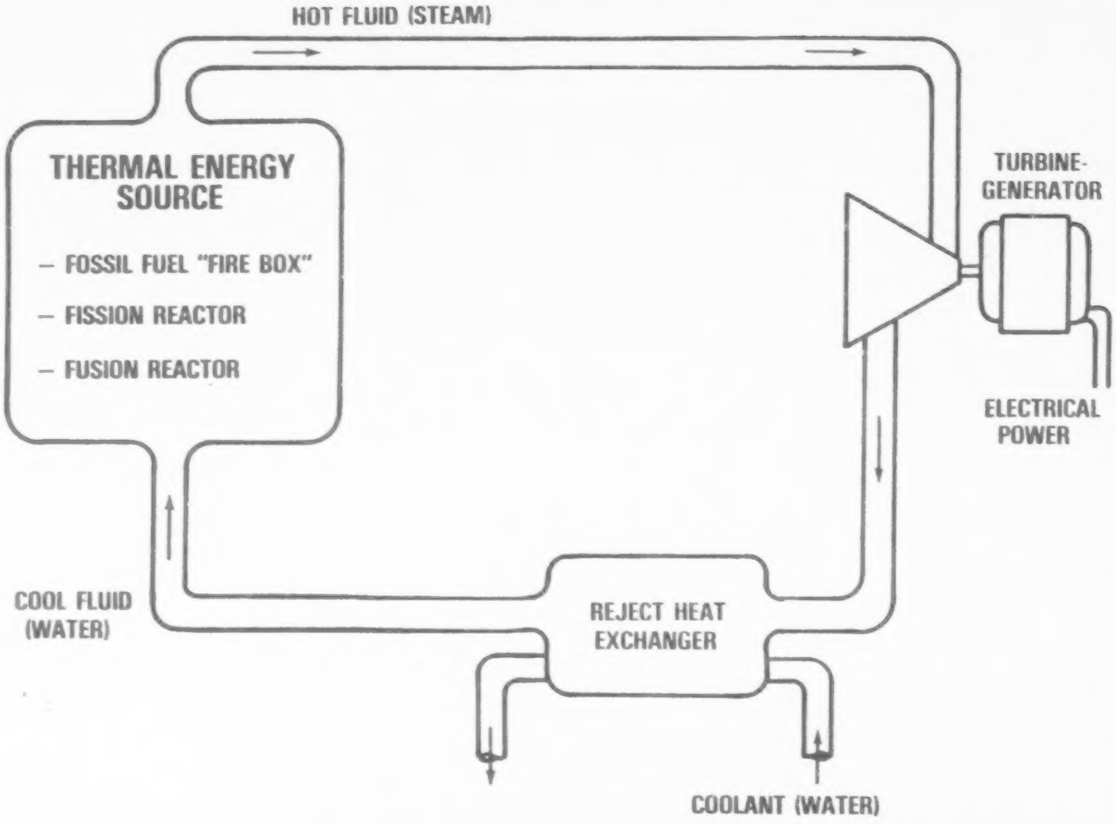
- PLASMA HEATING
- PLASMA CONFINEMENT
- MAGNET AND VACUUM SYSTEMS

PRODUCTS

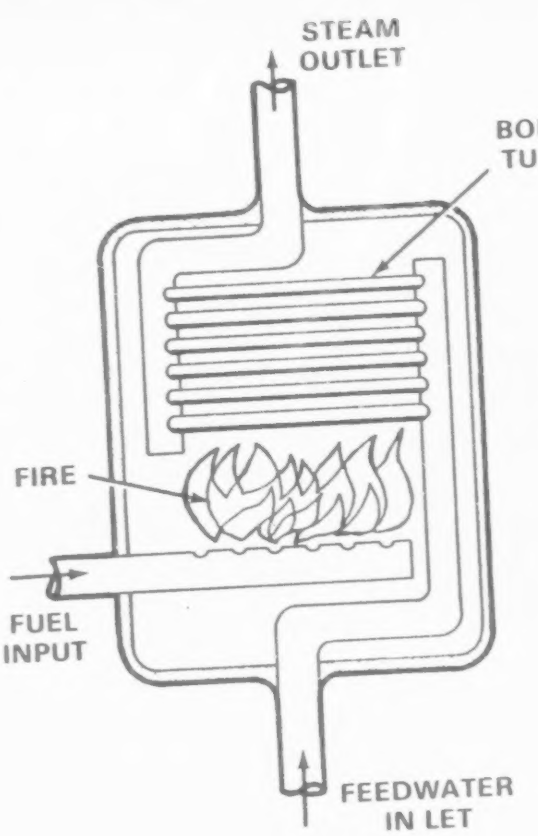
- HEAT TRANSFER
- ASH REMOVAL
- MATERIALS

THREE CONFINEMENT APPROACHES

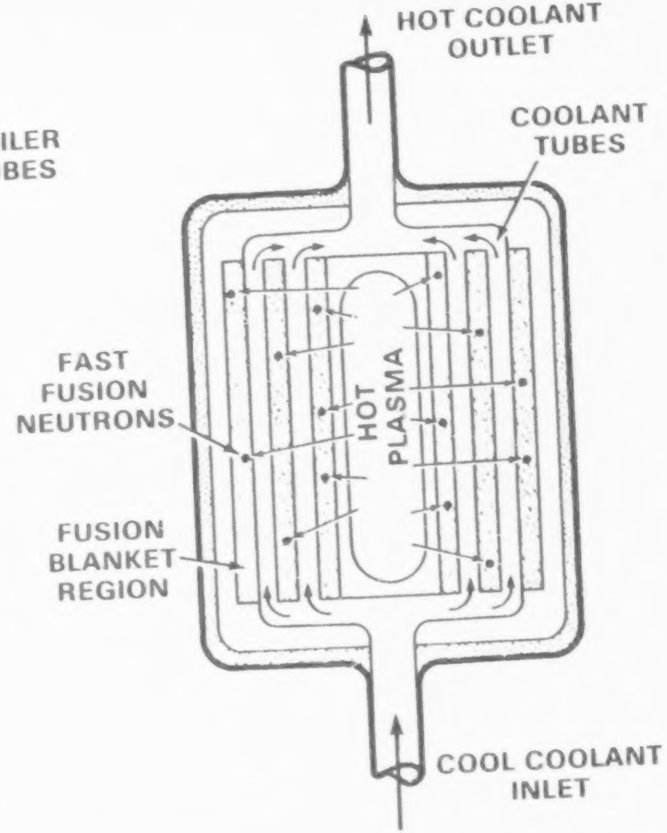




ELECTRICAL POWER PLANT SCHEMATIC

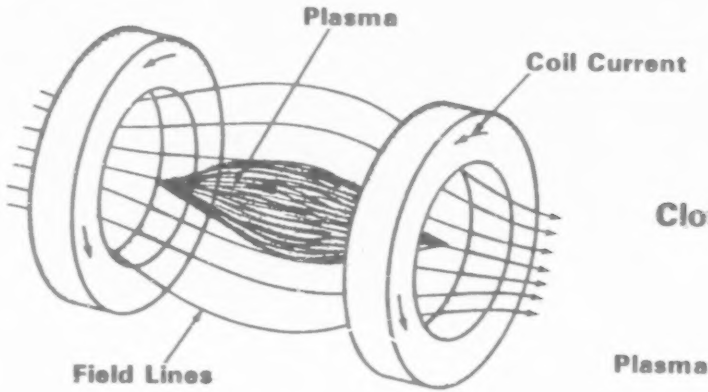


FOSSIL FUEL "FIRE BOX"



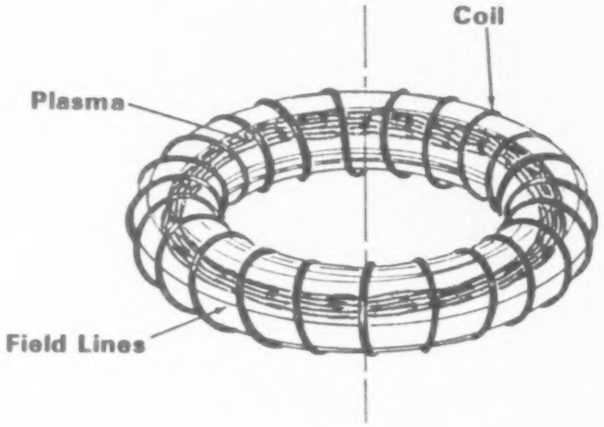
FUSION "FIRE BOX"

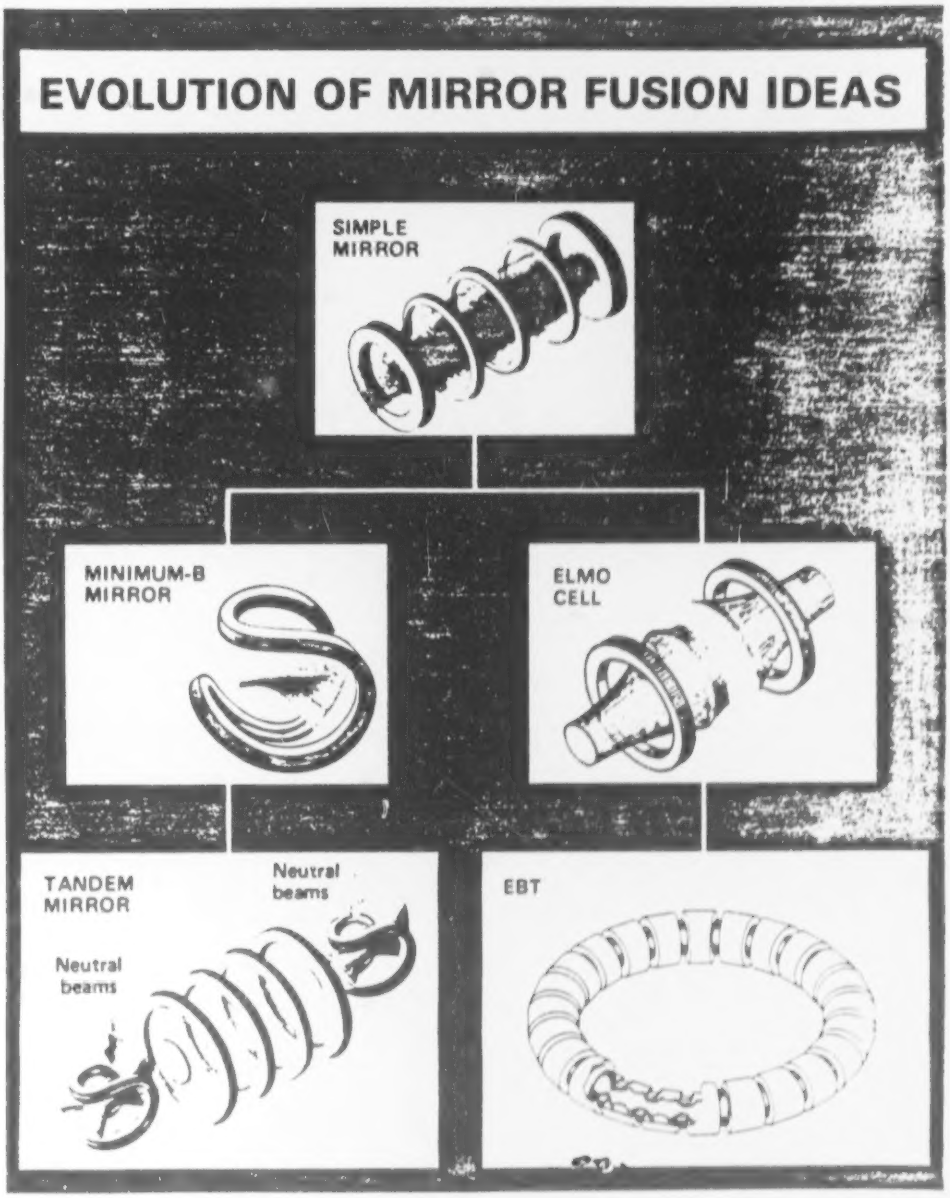
THERE ARE TWO BASIC MAGNETIC FIELD CONFIGURATIONS FOR CONFINING PLASMAS



Open System -
Simple Magnetic Mirror

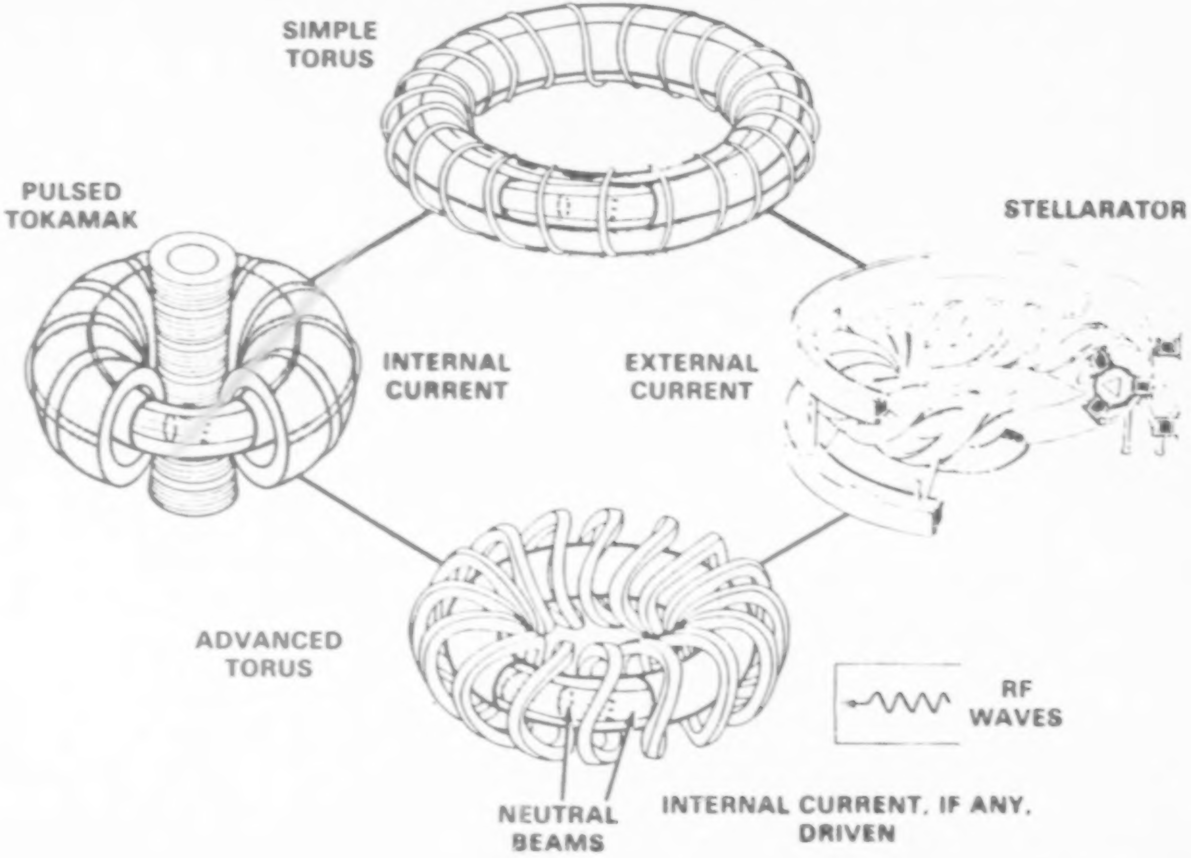
Closed System - Simple Torus





EVOLUTION OF MIRROR FUSION IDEAS

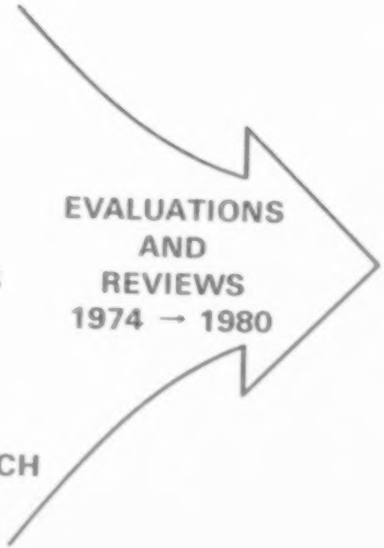
EVOLUTION OF TOROIDAL FUSION IDEAS



CONVERGENCE TO MOST PROMISING CONCEPTS

EXPERIMENTS SUPPORTED IN EARLY 1970'S

TOKAMAK
MIRROR
SCYLLAC
ASTRON
THETA PINCH
TORMAC
LINUS
ELMO BUMPY TORUS
LINEAR SOLENOIDS
FAST LINER
ION RINGS
MULTIPOLES
REVERSED FIELD PINCH
CUSPS
Z PINCH



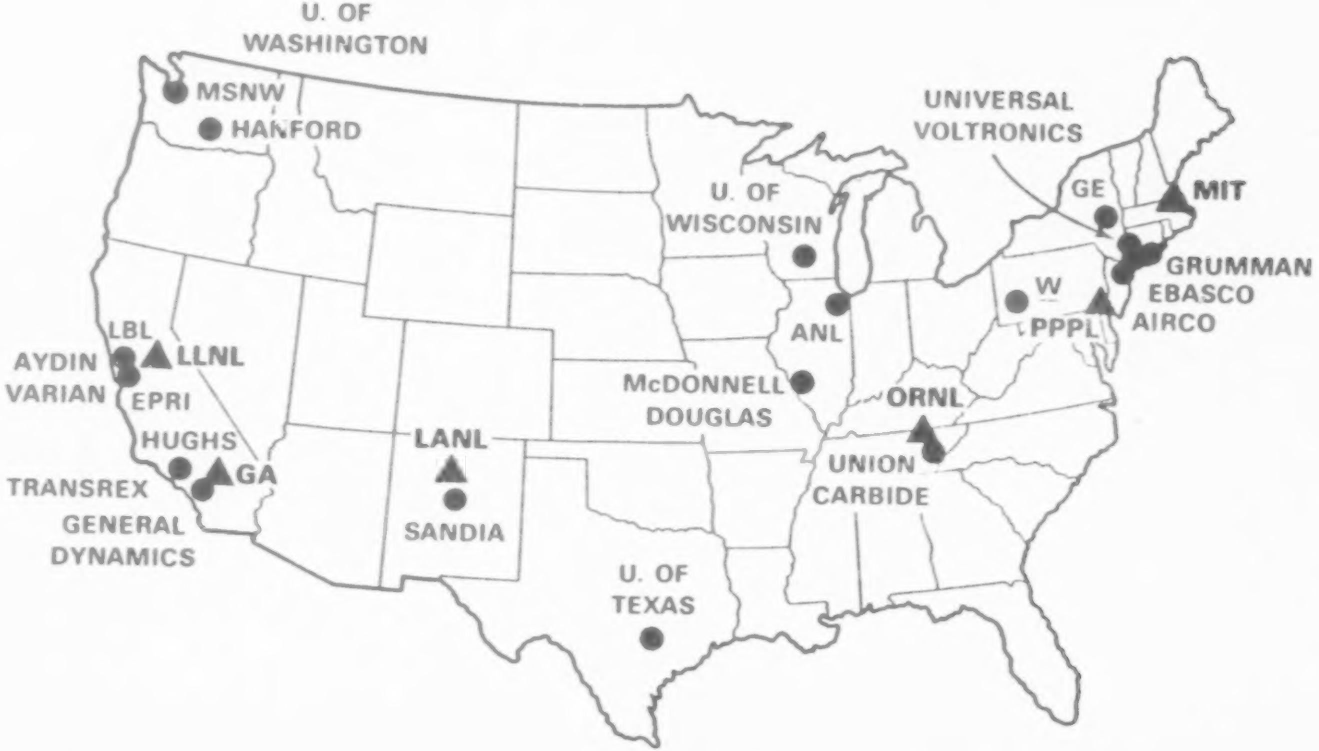
EVALUATIONS
AND
REVIEWS
1974 → 1980

EXPERIMENTS SUPPORTED IN EARLY 1980'S

TOKAMAK
TANDEM MIRROR
ELMO BUMPY TORUS

COMPACT TOROIDS
REVERSE FIELD PINCH

FUSION PROGRAM PARTICIPANTS



MAJOR FUSION R&D CENTERS

MAJOR CONTRACTORS	EMPHASIS	TOTAL FY 83 PRESIDENTIAL BUDGET (BA $ IN MILLIONS)	PERCENT
PRINCETON	TOKAMAKS	130.9	29
OAK RIDGE	TOKAMAKS, EBT, TECHNOLOGY	79.2	18
LAWRENCE LIVERMORE	MIRRORS	96.3	22
GENERAL ATOMIC	TOKAMAK	28.9	7
LOS ALAMOS	ALTERNATE CONCEPTS	20.0	4
MIT	TOKAMAK, MIRROR	23.4	5
OTHERS*		43.3	10
UNIVERSITIES		22.1	5
		$ 444.1	100%
(TOTAL INDUSTRY, EST.)		(186)	(42%)

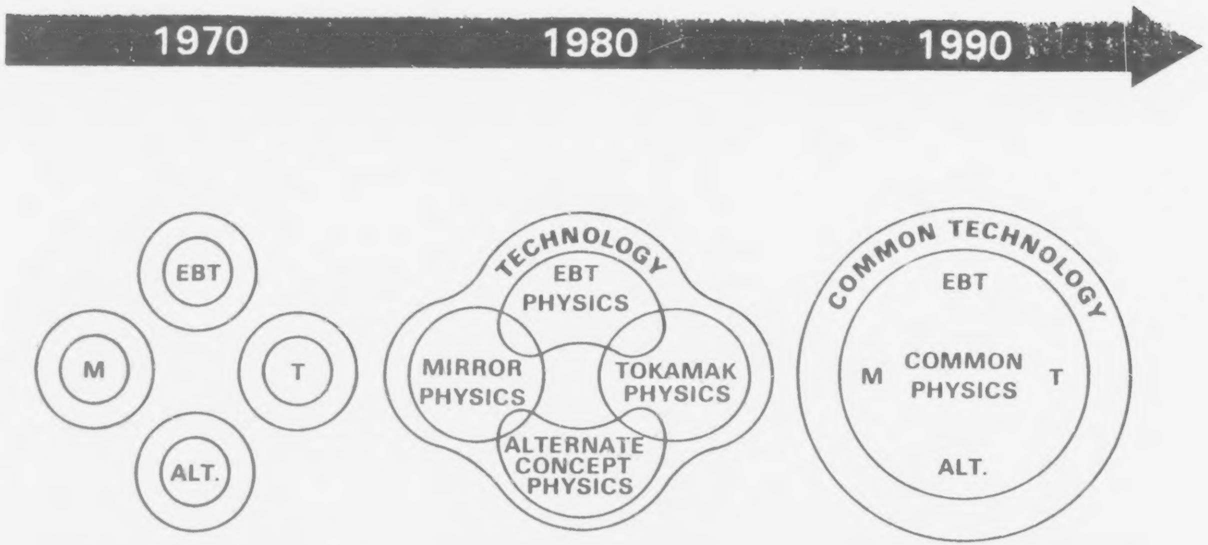
*INCLUDES: ANL, BNL, LBL, HEDL, PNL, INEL, SANDIA, DIRECT INDUSTRIAL CONTRACTS (EXCLUDING GA) AND PROGRAM DIRECTION

THE PRESENT FEDERAL ROLE IS TO ESTABLISH SCIENTIFIC AND ENGINEERING FEASIBILITY

- ESTABLISHING SCIENTIFIC FEASIBILITY INCLUDES DEVELOPING A RANGE OF SCIENTIFIC CONCEPTS SUITABLE FOR PRACTICAL APPLICATION.

- ESTABLISHING THE ENGINEERING FEASIBILITY OF FUSION MEANS PROVIDING THE BASIC TECHNOLOGY DATA FOR INDUSTRIAL RISK ASSESSMENT.

CONVERGENCE OF FUSION SCIENCE AND TECHNOLOGY



1970

1980

1990

EBT

M

T

ALT.

TECHNOLOGY

EBT PHYSICS

MIRROR PHYSICS

TOKAMAK PHYSICS

ALTERNATE CONCEPT PHYSICS

COMMON TECHNOLOGY

EBT

M

COMMON PHYSICS

T

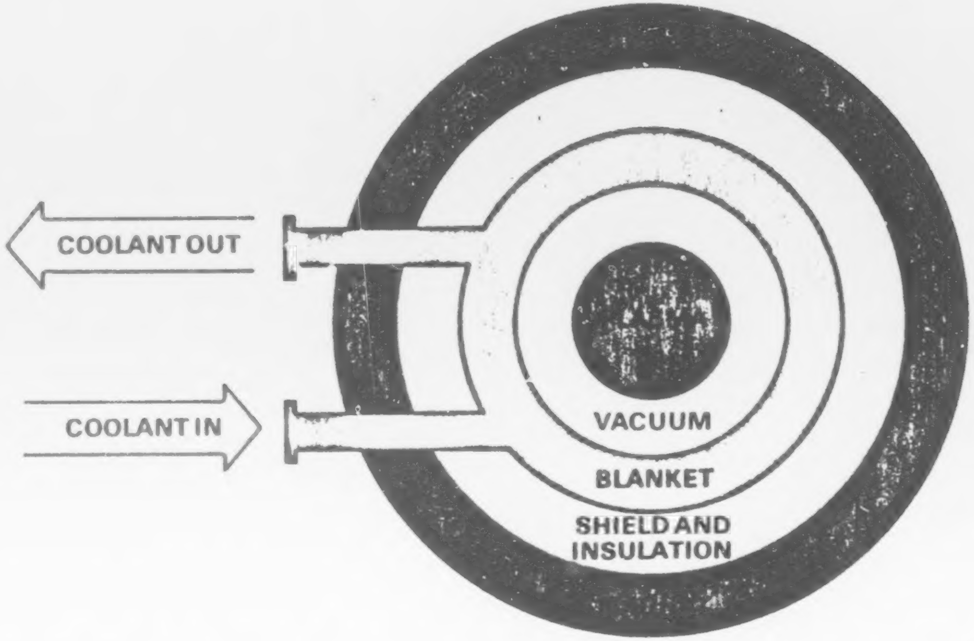
ALT.

SEPARATE APPROACHES
WITH SEPARATE
TECHNOLOGY

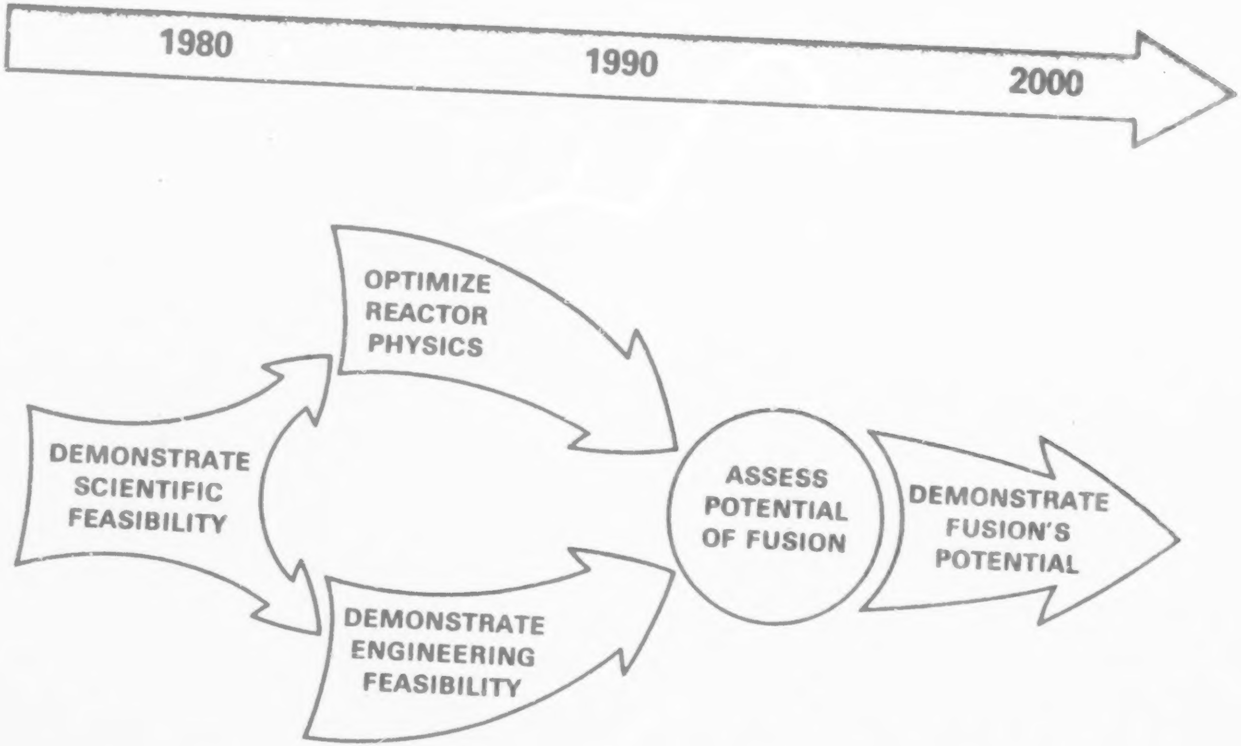
CONVERGING SCIENCE
WITH COMMON
TECHNOLOGY

GENERIC FUSION
REACTOR ENGINEERING
BASE

BASIC FUSION REACTOR CONFIGURATION



FUSION PROGRAM LOGIC



1980

1990

2000

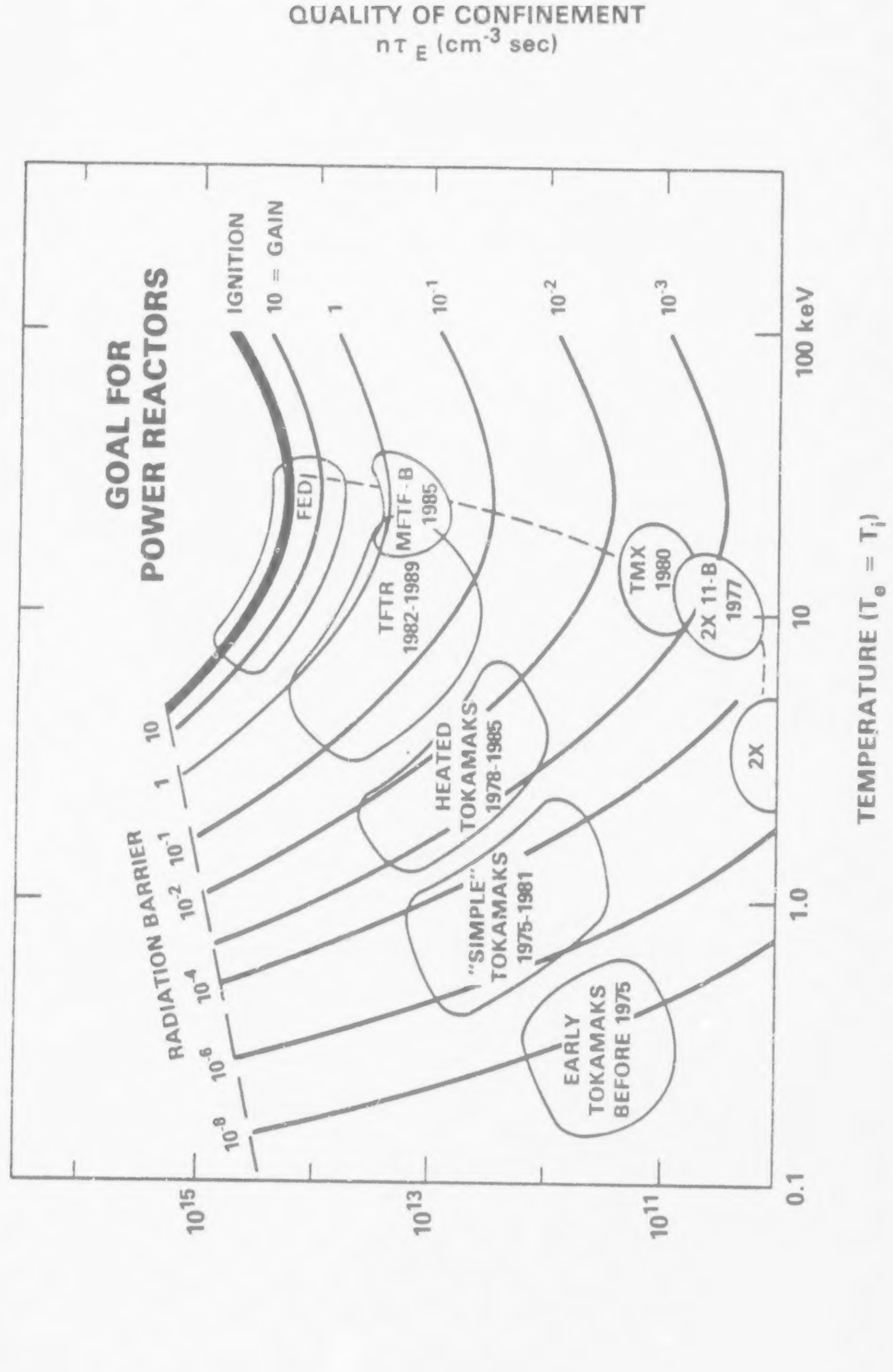
DEMONSTRATE
SCIENTIFIC
FEASIBILITY

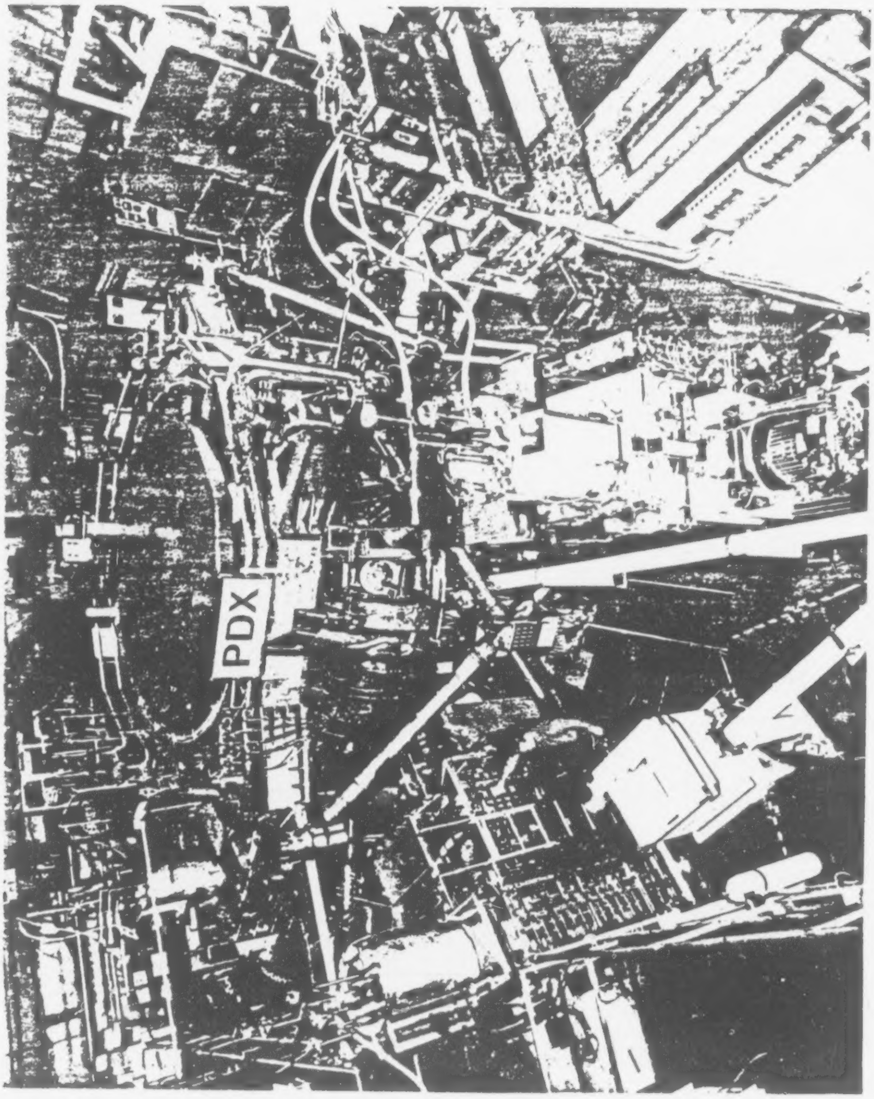
OPTIMIZE
REACTOR
PHYSICS

DEMONSTRATE
ENGINEERING
FEASIBILITY

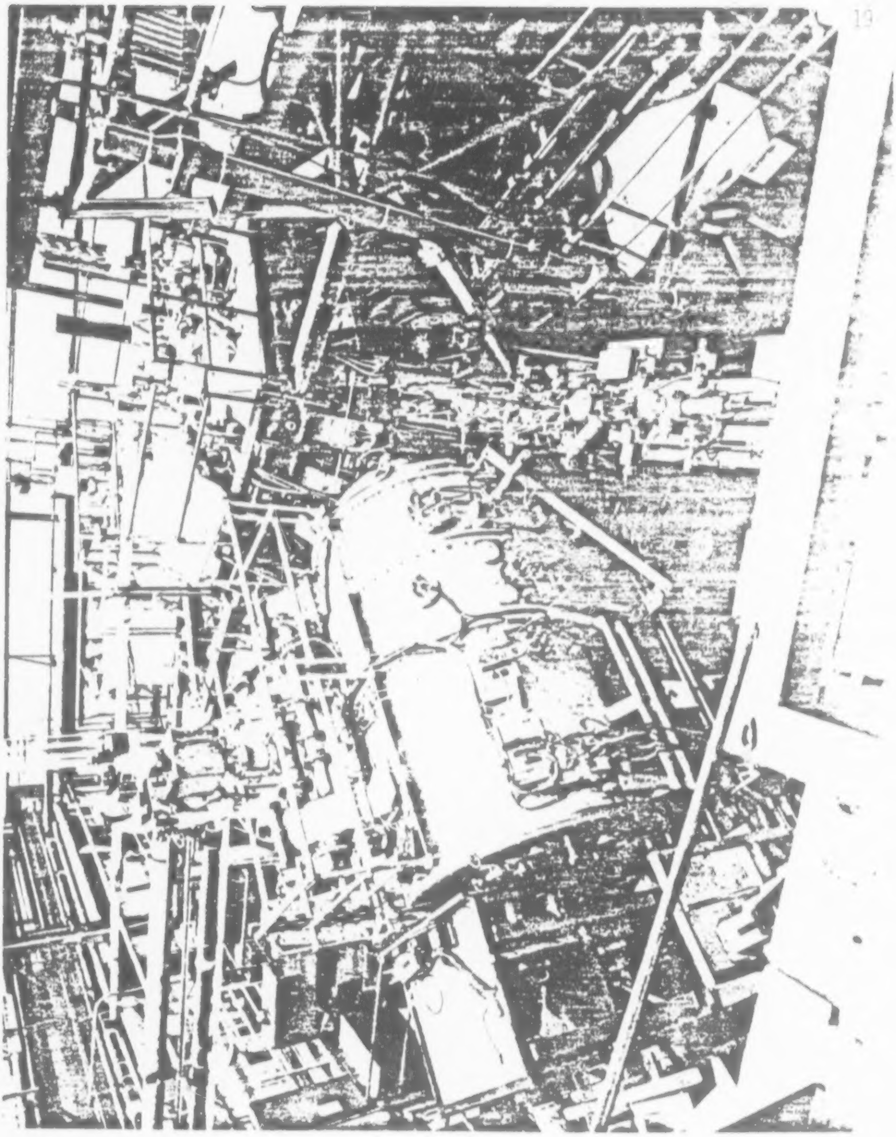
ASSESS
POTENTIAL
OF FUSION

DEMONSTRATE
FUSION'S
POTENTIAL


QUALITY OF CONFINEMENT
nτ E (cm-3 sec)
GOAL FOR POWER REACTORS
IGNITION
10 = GAIN
1
10-1
10-2
10-3
FED
MFTF-B 1985
TFTR 1982-1989
TMX 1980
2X 11-B 1977
HEATED TOKAMAKS 1978-1985
"SIMPLE" TOKAMAKS 1975-1981
2X
EARLY TOKAMAKS BEFORE 1975
RADIATION BARRIER
10
1
10-1
10-2
10-4
10-6
10-8
1015
1013
1011
0.1
1.0
10
100 keV
TEMPERATURE (Te = Ti)

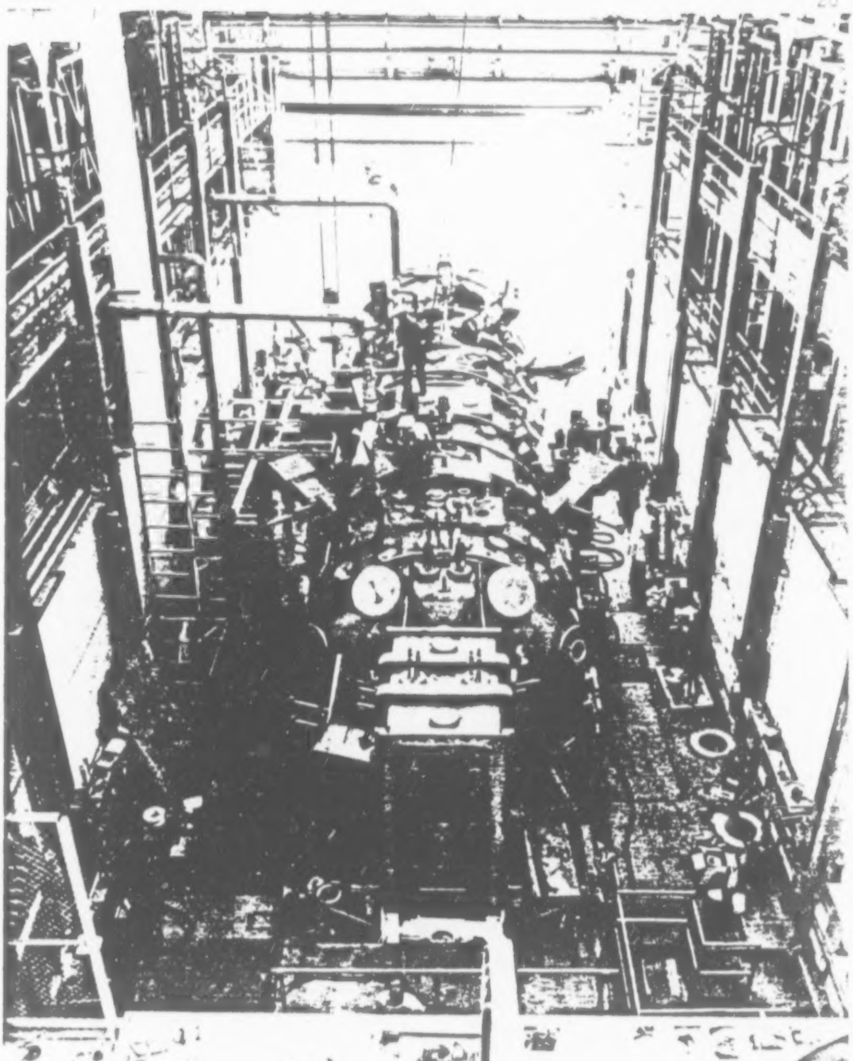


POLOIDAL DIVERTOR EXPERIMENT



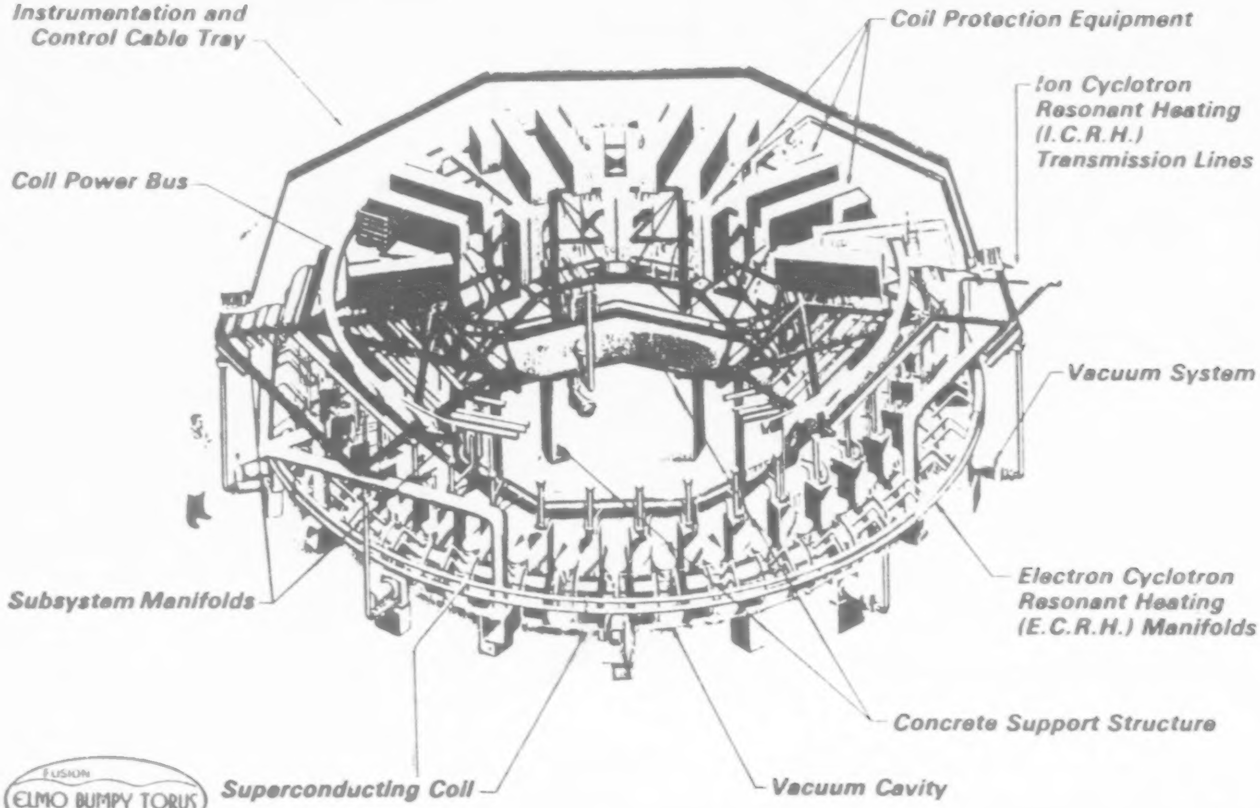
19

DOUBLET-III

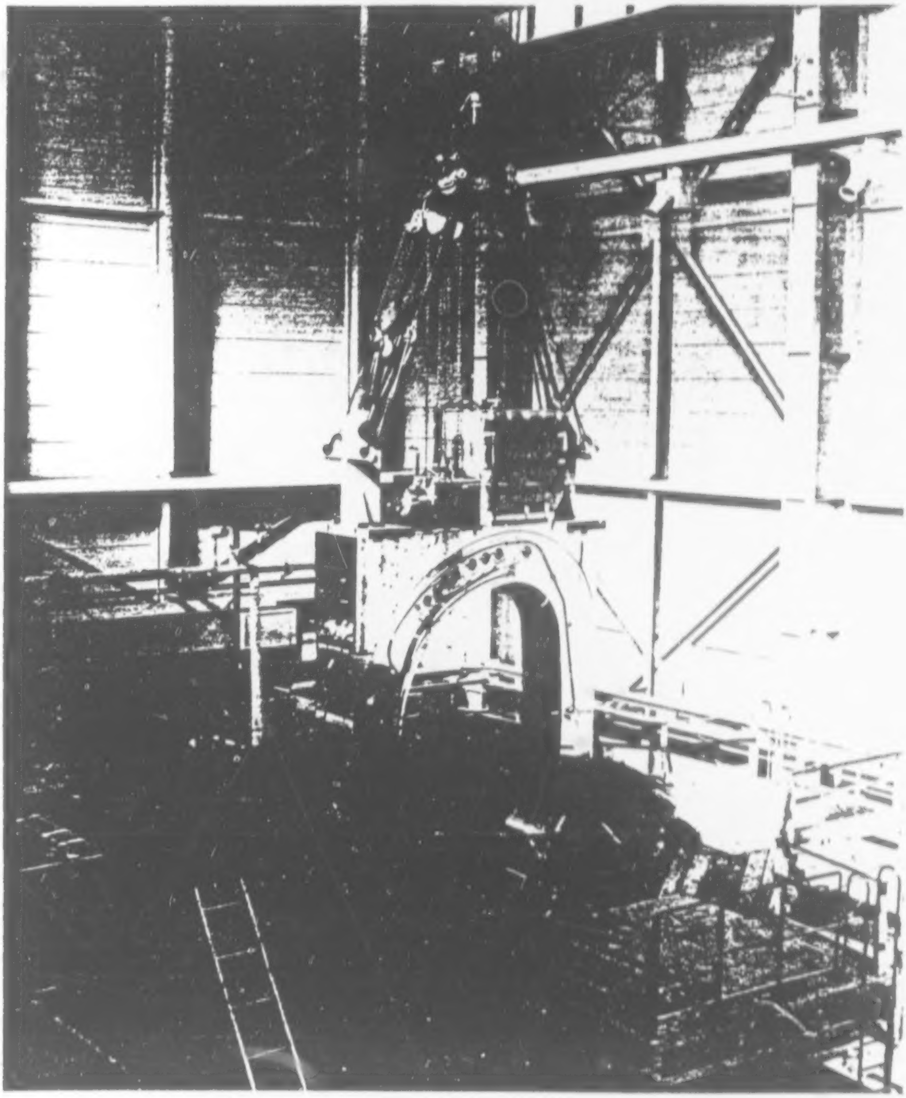


TANDEM MIRROR EXPERIMENT-UPGRADE

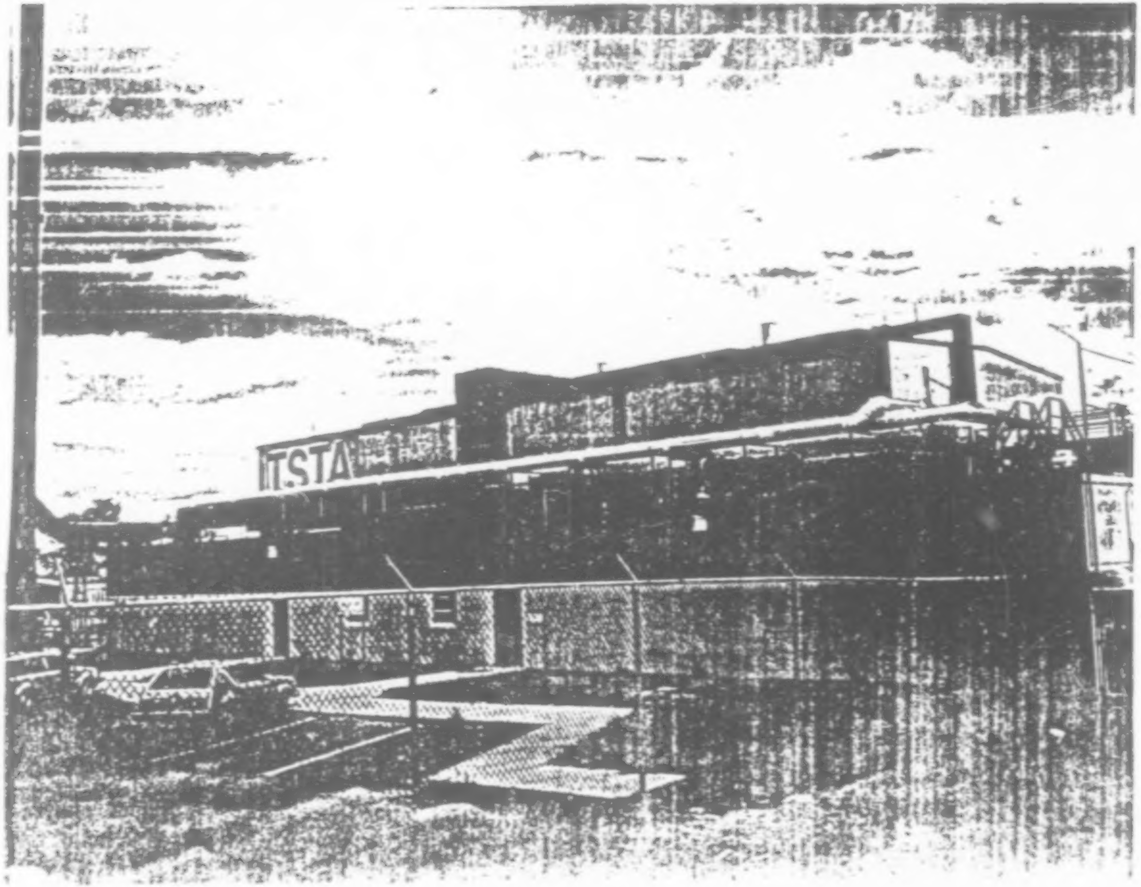
Elmo Bumpy Torus — Proof of Principle Experiment


Instrumentation and Control Cable Tray
Coil Protection Equipment
Ion Cyclotron Resonant Heating (I.C.R.H.) Transmission Lines
Coil Power Bus
Vacuum System
Subsystem Manifolds
Electron Cyclotron Resonant Heating (E.C.R.H.) Manifolds
Concrete Support Structure
Superconducting Coil
Vacuum Cavity

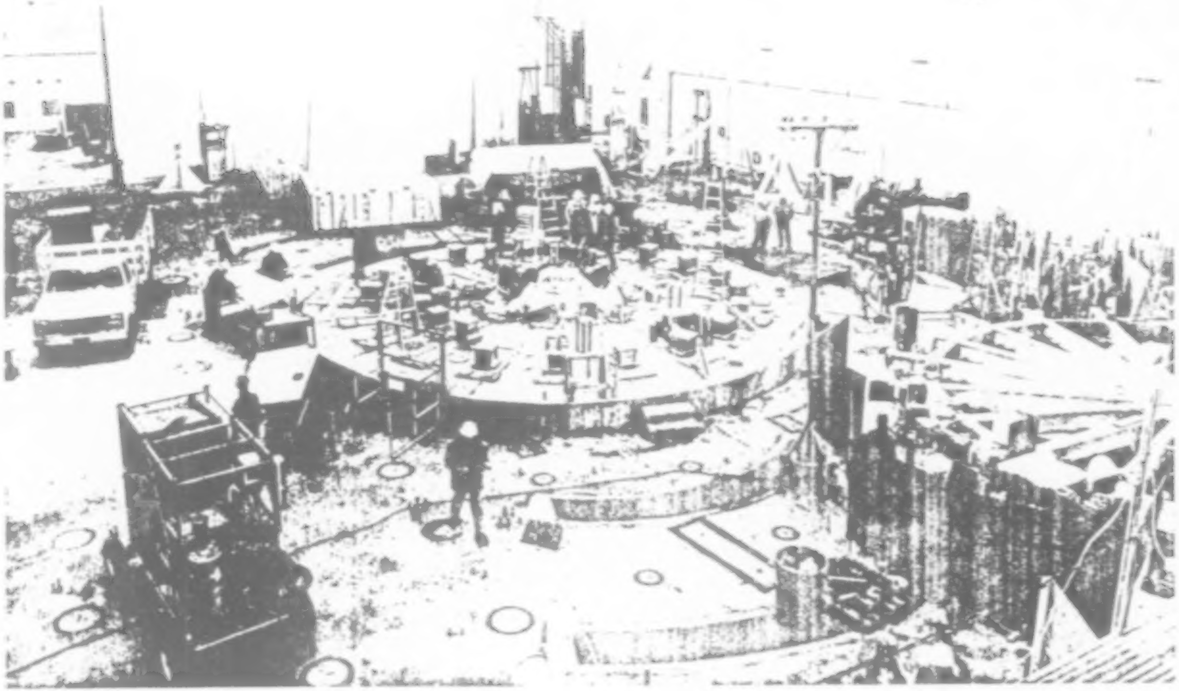
FUSION
ELMO BUMPY TORUS
ENERGY



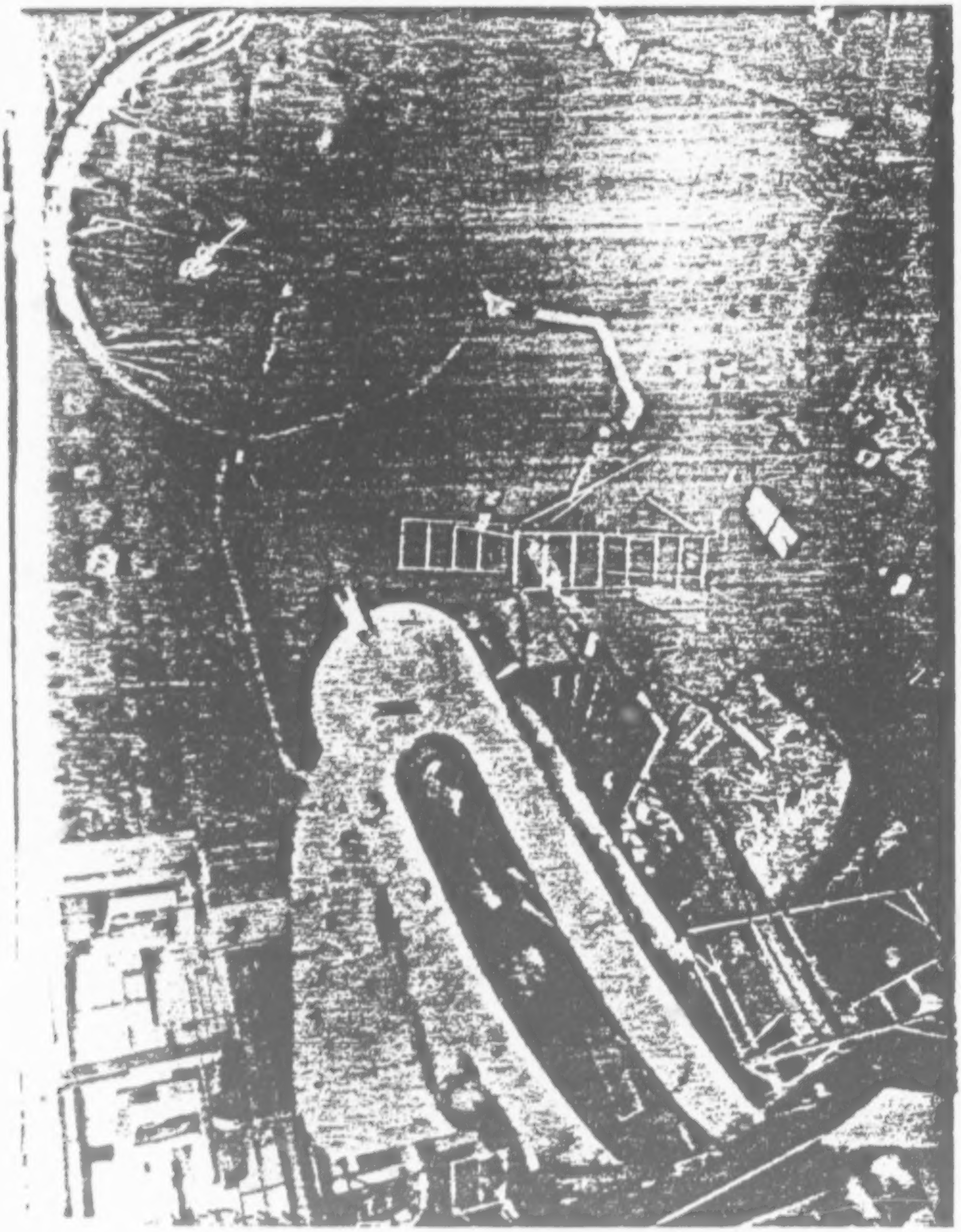
JAPANESE COIL

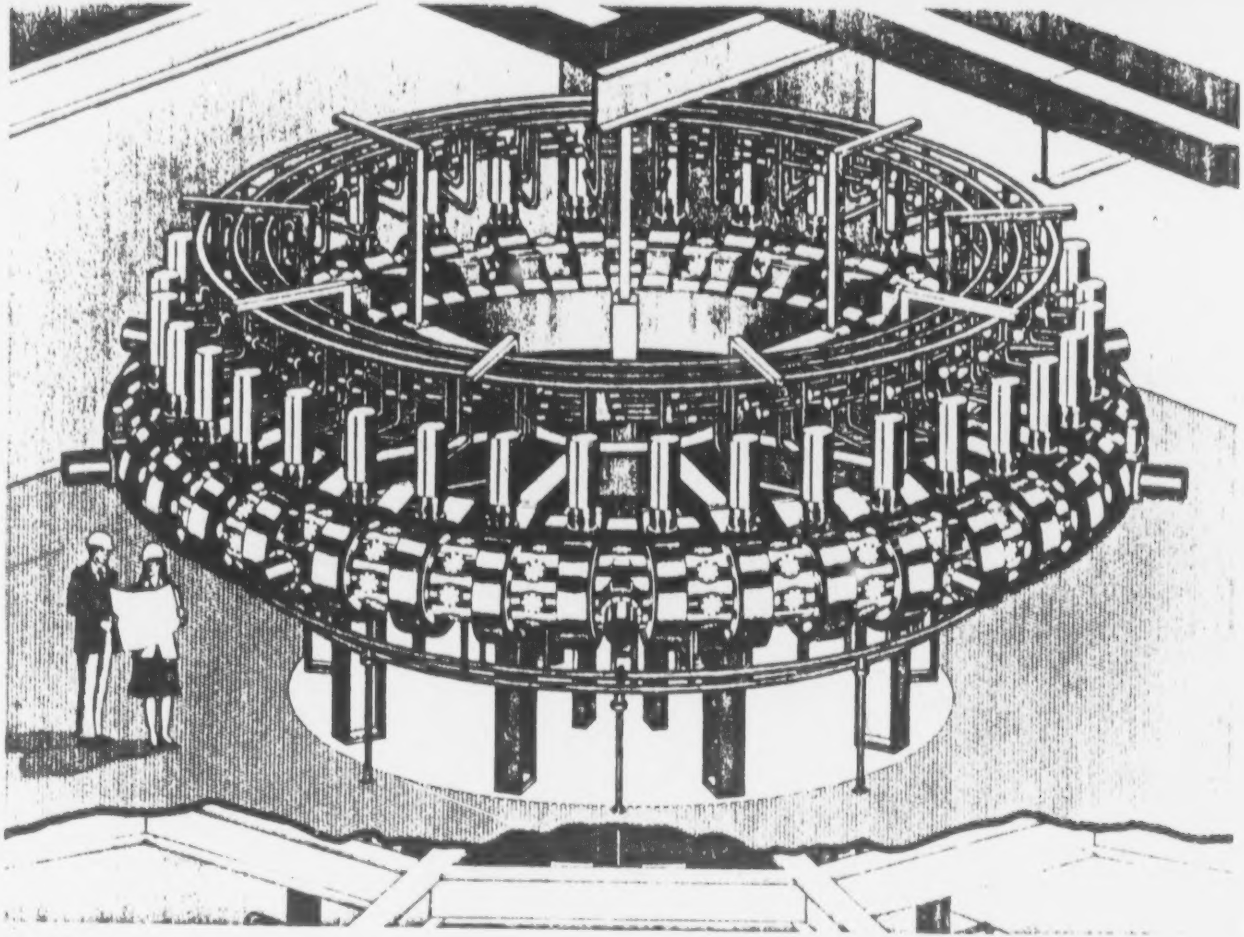

T.STA

29



TFTR PROJECT
PRINCETON, N.J.





FY 1983 Congressional Budget
Magnetic Fusion Energy
B/A in Thousands

	FY 1981	FY 1982 Reagan Request	FY 1983 Request	Change
Operating Expenses				
Applied Plasma Physics	$ 65,800	$ 67,400	$ 73,300	$ 5,900
Confinement Systems	92,262	124,470	181,000	56,530
Development and Technology	59,080	61,650	74,300	12,650
Center for Magnetic Fusion Energy	3,520	9,150	0	(- 9,150)
Planning and Projects	34,500	26,130	26,000	(- 130)
Program Direction	3,117	3,900	4,000	100
Subtotal	258,279	292,700	358,600	65,900
Capital Equipment	36,900	42,000	39,500	(- 2,500)
Construction				
Elmo Bumpy Torus-P	5,400	13,446	0	(-13,446)
Impurity Studies Exp.-C	4,500	0	0	0
Large Coil Test Facility	6,500	6,000	0	(- 6,000)
Tokamak Fusion Test Reactor	30,000	40,100	0	(-40,100)
Fusion Materials Irradiation Test Facility	22,600	14,000	0	(-14,000)
Mirror Fusion Test Facility-B	25,000	39,858	40,000	142
General Plant Projects	4,400	5,700	6,000	300
Subtotal	98,400	119,104	46,000	(-73,104)
Total Magnetic Fusion Energy	$393,579	$453,804	$444,100	$- 9,704

Figure 27

Magnetic Fusion Energy
FY 1983 Congressional Budget
Base Program Summary
B/A in Millions

	FY 1981	FY 1982	FY 1983 Request	Change
Applied Plasma Physics				
Operating Expenses	$ 61.8	$ 67.4	$ 73.3	$+ 5.9
Capital Equipment	5.4	6.2	4.0	- 2.2
Subtotal	67.2	73.6	77.3	+ 3.7
Confinement Systems - Tokamaks				
Operating Expenses	54.3	53.8	68.7	+14.9
Capital Equipment	6.9	6.6	7.6	+ 1.0
Subtotal	61.2	60.4	76.3	+15.9
Confinement Systems - Mirrors				
Operating Expenses	24.4	30.7	39.3	+ 8.6
Capital Equipment	6.4	5.2	6.2	+ 1.0
Subtotal	30.8	35.9	45.5	+ 9.6
Development and Technology				
Operating Expenses	53.6	57.6	67.2	+ 9.6
Capital Equipment	6.6	9.3	7.1	- 2.2
Subtotal	60.2	66.9	74.3	+ 7.4
Center for Magnetic Fusion Energy	3.5	9.1	0	- 9.1
Program Direction	3.1	3.9	4.0	+ 0.1
Total Base Program	$226.0	$249.8	$277.4	$+27.6

Figure 28

Magnetic Fusion Energy
FY 1983 Congressional Budget
Project Summary
B/A in Millions

	FY 1981	FY 1982	FY 1983 Request	Change
TFTR				
Operating Expenses				
Operation R&D	$ 29.8	$ 37.4	$ 69.0	$+31.6
TFM	10.3	15.5	20.0	+ 4.5
Total Operating Expenses	40.1	52.9	89.0	+36.1
Capital Equipment	6.1	8.1	8.0	- 0.1
Construction	30.0	40.1	0	-40.1
Total TFTR	76.2	101.1	97.0	- 4.1
MFTF-B				
Operating Expenses	6.0	7.1	6.0	- 1.1
Construction	25.0	39.8	40.0	+ 0.2
Total MFTF-B	31.0	46.9	46.0	- 0.9
EBT-P				
Operating Expenses	2.0	4.0	4.0	0
Construction	5.4	13.4	0	-13.4
Total EBT-P	7.4	17.4	4.0	-13.4
FMIT				
Operating Expenses	8.0	2.0	0	- 2.0
Capital Equipment	0.7	0	0	0
Construction	22.6	14.0	0	-14.0
Total FMIT	31.3	16.0	0	-16.0
LCTF				
Operating Expenses	1.6	4.1	7.1	+ 3.0
Capital Equipment	1.8	3.4	2.6	- 0.8
Construction	6.5	6.0	0	- 6.0
Total LCTF	9.9	13.5	9.7	- 3.8
ISX-C				
Construction	4.5	0	0	0
GPE	4.4	5.7	6.0	+ 0.3
GPP	3.0	3.3	4.0	+ 0.7
Total Project Summary	$167.7	$203.9	$166.7	$-37.2

Figure 29

Magnetic Fusion Energy
FY 1983 Congressional Budget
Program Totals
B/A in Millions

	FY 1981	FY 1982	FY 1983 Request	Change
Operating Expenses	$ 255.2	$ 288.8	$ 354.6	$ 65.8
Capital Equipment	36.9	42.0	39.5	(- 2.5)
Construction	98.4	119.1	46.0	(-73.1)
Program Direction	3.1	3.9	4.0	0.1
Total	$ 393.6	$ 453.8	$ 444.1	$(- 9.7)

Figure 30

Magnetic Fusion Energy
FY 1983 Congressional Budget
Applied Plasma Physics Budget
B/A in Millions

	FY 1981	FY 1982	FY 1983 Request	Change
Operating Expenses				
Advance Fusion Concepts	$ 16.5	$ 17.3	$ 18.9	$ 1.6
Experimental Research	18.4	15.5	17.1	1.6
Theory	19.5	21.4	22.8	1.4
Computer Network	11.4	13.2	14.5	1.3
. Subtotal	65.8	67.4	73.3	5.9
Capital Equipment	6.4	6.2	4.0	(- 2.2)
Total Applied Plasma Physics	$ 72.2	$ 73.6	$ 77.3	$ 3.7

Figure 31

Magnetic Fusion Energy
FY 1983 Congressional Budget
Confinement Systems - Tokamaks
B/A in Millions

	FY 1981	FY 1982	FY 1983 Request	Change
Operating Expenses				
Research Operations	$ 52.0	$ 50.6	$ 58.5	$ 7.9
TFTR	10.6	36.0	69.0	33.0
MDF's	2.3	3.2	10.2	7.0
Subtotal	64.9	89.8	137.7	47.9
Capital Equipment				
TFTR	4.4	6.4	8.0	1.6
Other	6.9	6.6	7.6	1.0
Subtotal	11.3	13.0	15.6	2.6
Construction				
ISX-C	4.5	0	0	0
Total Confinement Systems - Tokamaks	$ 80.7	$ 102.8	$ 153.3	$ 50.5

Figure 32

Magnetic Fusion Energy
FY 1983 Congressional Budget
Confinement Systems - Mirrors
B/A in Millions

	FY 1981	FY 1982	FY 1983 Request	Change
Operating Expenses				
Research Operations	$ 15.2	$ 26.4	$ 32.7	$ 6.3
EBT-P	2.0	4.0	4.0	0
MDF's	10.2	4.3	6.6	2.3
Subtotal	27.4	34.7	43.3	8.6
Capital Equipment	6.4	5.2	6.2	1.0
Construction				
EBT-P	5.4	13.4	0	(- 13.4)
Total Confinement Systems - Mirrors	$ 39.2	$ 53.3	$ 49.5	$- 3.8

Figure 33

Magnetic Fusion Energy
FY 1983 Congressional Budget
Development and Technology
B/A in Millions

	FY 1981	FY 1982	FY 1983 Request	Change
Operating Expenses				
Magnets	$ 13.4	$ 15.0	$ 16.7	$ 1.7
Plasma Engineering	19.0	16.1	19.7	3.6
Reactor Materials	12.2	14.8	15.7	0.9
Fusion Systems Engineering	10.7	11.1	17.1	6.0
Environment and Safety	2.1	2.8	2.9	0.1
Fusion Energy Applications	1.7	1.9	2.2	0.3
Subtotal	59.1	61.7	74.3	12.6
Capital Equipment	8.4	12.7	9.7	(- 3.0)
Construction				
LCTF	6.5	6.0	0	(- 6.0)
Total Development and Technology	$ 74.0	$ 80.4	$ 84.0	$ 3.6

Figure 34

Magnetic Fusion Energy
FY 1983 Congressional Budget
Center for Magnetic Fusion Energy
B/A In Millions

	FY 1981	FY 1982	FY 1983 Request	Change
Operating Expenses				
Designs	$ 3.5	$ 9.1	$ 0	$(-9.1)
Total Center for Magnetic Fusion Energy	$ 3.5	$ 9.1	$ 0	$(-9.1)

Figure 35

Magnetic Fusion Energy
FY 1983 Congressional Budget
Planning and Projects
B/A in Millions

	FY 1981	FY 1982	FY 1983 Request	Change
Operating Expenses				
TFTR/TFM	$ 22.3	$ 17.0	$ 20.0	$ 3.0
MFTF-B	4.2	7.1	6.0	(- 1.1)
FMIT	8.0	2.0	0	(- 2.0)
Subtotal	34.5	26.1	26.0	(- 0.1)
Capital Equipment				
TFTR	0.7	1.6	0	(- 1.6)
MFTF-B	0	0	0	0
FMIT	0.7	0	0	0
GPE	3.0	3.3	4.0	0.7
Subtotal	4.4	4.9	4.0	(- 0.9)
Construction				
TFTR	30.0	40.1	0	(-40.1)*
MFTF-B	25.0	39.9	40.0	0.1
FMIT	22.6	14.0	0	(-14.0)
GPP	4.4	5.7	6.0	0.3
Subtotal	82.0	99.7	46.0	(-53.7)
Total Planning and Projects	$ 120.9	$ 130.7	$ 76.0	$(-54.7)

Figure 36

Mrs. BOUQUARD. Thank you very much, Dr. Clarke.

We have certainly heard a great deal lately about the alleged interference by OMB and OSTP in the budgetary decisions that the Department of Energy has made. How much interplay was there? How much interference was there by OMB and OSTP in making the decisions that you made, Dr. Trivelpiece? Just how deeply were they involved? Just how much of their input was based upon sound technical judgments?

Dr. Trivelpiece, I think, as I have said before in other hearings, that OMB's involvement in this activity has been somewhat overrated.

Just what was their involvement?

Dr. TRIVELPIECE. The Office of Management and Budget did provide what the Department requested in the way of a budget. There was no change in the overall budget in the pass-back.

During the period in which the budget was being formulated, we were trying to address the overall budget constraints which the Department was going to have to face. There was some concern that in the future there may be a period of constrained budgets. Under those circumstances, it was felt that perhaps we should examine the relationship between operation and construction funds.

We did, and we agree that the program as we have modified it does more appropriately meet the needs of the future. However, OMB's involvement in that, I think, is not as strong as might be indicated by some of the activities that have been in the press.

Mrs. BOUQUARD. Well, instead of an increase of 25 percent, we have a reduction of $10 million. Is that not correct?

Dr. TRIVELPIECE. Well, it is slightly less than that, but, yes.

Mrs. BOUQUARD. Well, are we really going to make a proper evaluation of the two mainline magnetic fusion technologies? Aren't we really going to delay the MFTF-B by approximately 3 years? Are the tokamak and mirror devices going to be at the same pace? Are they going to be developed at the pace so that we can properly evaluate the two technologies?

Dr. TRIVELPIECE. I believe so, but perhaps Dr. Clarke would like to respond to that.

Mrs. BOUQUARD. Is this a slowdown of approximately 3 years, Dr. Clarke?

Dr. CLARKE. Madam Chairman, it is difficult to say exactly what the slowdown is. It depends on how much money we can provide in out-year budgets. To complete a project, the thing that counts is the integrated budget profile.

At present, we hope to be able to provide money in the 1984 budget to try to minimize the delay of that MFTF-B project. However, until we formulate the fiscal year 1984 budget, it is difficult to say exactly what delays will take place.

Mrs. BOUQUARD. But this $25 million did go for other projects. Is that not correct?

Dr. CLARKE. That is correct. The $25 million which was shifted from construction projects was used to support the operating budget of the program. It was used to support the operations of all of those facilities that I showed you in the viewgraphs, the facilities from which we are gaining most of our scientific progress in the near term.

Mrs. BOUQUARD. In Japan, we see a great deal of industrial involvement. How are you planning to involve industry in our magnetic fusion program? What are the plans in this area, Dr. Clarke?

Dr. CLARKE. Well, I have just returned from Japan where I spent a considerable amount of time talking to the people that run the Japanese program. They do use industry in a slightly different way than we do in this country. However, I——

Mrs. BOUQUARD. How are we planning to involve industry in our fusion program?

Dr. CLARKE. Well, we do. I would like to emphasize that we do involve industry in our program today. Currently, we spend approximately $186 million a year in industry. The difference between the U.S. program and the Japanese program with respect to industry is that the Japanese tend to give major systems responsibility for a project to their industry, whereas, to date, U.S. industry has been involved largely in the mode of manufacturing components for our experiments.

Over the last few years, we have made efforts to involve industry more at the system level. As you are aware, the McDonnell Douglas Corp. has the major systems responsibility for the EBT–P project which we are hoping to continue in our program.

Mrs. BOUQUARD. But aren't the cutbacks going to interfere with industry's involvement in the program?

Dr CLARKE. Yes. This is going to be inevitable. However, even though we do have a relatively flat-level-of-effort situation in fusion right now, that doesn't mean that we are going to turn our backs on industry.

I would like to see more industrial involvement in the fusion program because we need the industrial expertise and they need to learn enough about fusion to make that evaluation of fusion potential that I talked about before.

In a flat-budget situation, the only thing that we can do to involve industry more directly or more heavily is to increase the quality of their participation rather than the quantity.

As I have emphasized, the major portion of the scientific program is in the national laboratories, and it must remain in the national laboratories until we reach the point at which we know which is the appropriate fusion system to be developed. We are not at that point yet.

Mrs. BOUQUARD. I am very interested in what can be accomplished on the international front and what you are doing to increase international cooperation in our programs.

Dr. CLARKE. Well, international cooperation has always been a strong feature of the magnetic fusion program worldwide. I indicated in my testimony a number of fusion systems which were developed overseas which are now the mainstay of the U.S. program.

In times of constrained budgets, we are trying to make better use of international cooperation in the sense of negotiating with foreign countries to have them put their development efforts into those areas that we are not able to afford at the present time. We hope that we will develop on a worldwide base a more comprehensive knowledge of fusion technology and fusion science.

I would be happy to submit for the record a complete listing of our international cooperative efforts. They are quite extensive and involve the Soviet Union in a somewhat restrictive manner at the present time—but they involve the European community and Japan.

Mrs. BOUQUARD. Thank you very much. Without objection, I would like for that list to be included in the record.

[Material supplied follows:]

A Listing of Fusion Program Activities in International Cooperation

Specific Areas

Science

● Stellarators (US-EC[1], US-J[2])

● Bumpy Torus (US-J[2])

● Theory Institute (US-J[2])

● Reversed Field Pinch (US-IEA-EC[3])

● Compact Tori (US-J[2], US-USSR[4], US-EC[1])

● Mirror (US-J[2], US-USSR[4])

● Tokamak (US-J[2], US-EC[1], US-USSR[4]) includes Doublet-III Joint Program (five years, $70M investment by J)

○ University-oriented Fusion Science (US-PRC[5])

● Specialized Topics (laboratory-to-laboratory)

Technology

● Superconducting Coils (IEA[3]) (Large Coil Task)

● Plasma-wall Interaction (IEA[3]) (Textor)

● Materials Irradiations (US-J[2], IEA[3]) includes RTNS-II Joint Program (5 years, $9M investment by J)

○ Nuclear Topics (US-J[2], US-EC[1]) (Blanket, Shield, etc.)

○ Pulsed S/C Coils (US-J[2])

○ Other Technology Development (US-J[2])

○ FMIT Project Construction (US-IEA[3])

System Integration Studies

● INTOR (IAEA[6])

● Large Tokamak Devices (IEA[3], IAEA[6])

● Topical and General Meetings (IAEA[6])

○ FED/FER Comparison (US-J[2])

○ FED/NET Comparison (US-EC[1])

General Areas

Active participation in coordination committees for each arrangement, IAEA, IEA, US-USSR, US-J.

Additionally, informal scientific liaisons with other country's laboratories.

Discussions with European Community, Canada and Peoples Republic of China about potential bilaterals.

Notes to Listing

● - Cooperation essential to U.S. program success in this area.

◓ - Cooperation helpful to U.S. program success.

O - Cooperation being seriously considered.

1. Informal, official arrangements.
2. Within formal, US-J bilateral on energy.
3. Within formal IEA arrangements.
4. Within formal, US-USSR bilateral on atomic energy.
5. Within formal, US-PRC bilateral on energy.
6. Within formal IAEA arrangements.

Mrs. BOUQUARD. Mr. Volkmer?

Mr. VOLKMER. Thank you. Madam Chairman, I would like to continue just a little bit on the implications of this year's budget, and projections for the future in relation to last year's budget. In other words, I would like to get into where the cuts are and where that puts us.

Now, as I understand, you have said that you haven't prepared your 1984 budget, so you don't know where you are as far as 1984 is concerned. Is that correct?

Dr. CLARKE. That is correct, sir.

Mr. VOLKMER. So we don't know whether there will be any construction funds in for these other projects or not in 1984. Is that correct?

Dr. CLARKE. That is correct.

Mr. VOLKMER. And if there are no construction funds in 1983 and none in 1984, how are we going to keep these teams together?

Dr. CLARKE. Well, perhaps I should address the specifics. There are three projects under discussion here. There is the MFTF at Livermore——

Mr. VOLKMER. Yes.

Dr. CLARKE [continuing]. Which is delayed, but certainly, it is intended to be continued. That project has over $40 million in it this year, and we anticipate that we will be able to provide substantial funding for that project in fiscal year 1984.

The EBT project at Oak Ridge has sufficient funds in our present budget and in the budget proposal for 1983 to maintain the project team through fiscal year 1983. We don't at this point know how much money will be available for that project in fiscal year 1984.

With regard to the FMIT project, we have provided sufficient funds in the fiscal year 1982 budget to continue the development of the basic accelerator system, the target system, and to finish the design of that project. We are exploring with Europe and Japan the possibilities of gaining international support for that project.

Therefore, it is somewhat of a complicated picture. There are a lot of imponderables in the question of whether or not we will be able to continue each of these projects and at exactly what pace we will continue them.

Mr. VOLKMER. Now, we all agree, I think, that this is still basic research, is it not?

Dr. CLARKE. I don't think that is exactly the correct term, sir. Fusion is a mission-oriented program.

Mr. VOLKMER. All right.

Dr. CLARKE. Everything that we do in the program is oriented toward producing some sort of an effective practical power system in the long run.

There is a considerable amount of basic research required in the program, but there is also a lot of applied technology contained within the present program.

Mr. VOLKMER. But it is not ready for commercial application?

Dr. CLARKE. That is correct.

Mr. VOLKMER. We are way down the road before we get there, if we get there. Is that correct?

Dr. CLARKE. That is correct.

Mr. VOLKMER. And that is why I don't understand why we are seeing the cutbacks in the program when, to me, it is still primarily basic research, even though you disagree. It is one of those things that I think we should continue for sure at a little faster pace than what this budget proposes.

Dr. CLARKE. Well, I think that you have put your finger exactly on the issue. What we have here is a question of pace.

Mr. VOLKMER. Yes.

Dr. CLARKE. The present proposed budget for fiscal year 1983 will maintain the core of the program, the people who have brought the program to the present level of sophistication.

Under the overall priority for Federal budgets we cannot expand this program at the present time at any faster pace than what is proposed.

Mr. VOLKMER. That is within the funds that you have been provided for magnetic fusion energy use?

Dr. CLARKE. That is correct, sir.

Mr. VOLKMER. What is the basis for the increases in the operating expenses? Are those as the result of increased development within the existing facilities?

Dr. CLARKE. That is correct, sir. Over the past 10 years, we have developed a number of very expensive sophisticated facilities and we have tried to maintain the operating budget at a constant level of effort. Over the past 2 years, the operating portion of our program has been essentially level of effort.

The reason for maintaining that level of effort is to make efficient use of our past capital investment.

Mr. VOLKMER. Thank you, Madam Chairman. I don't—well, I do have one other question. I don't know if you could answer it. Maybe I could write to the Secretary and find out. I find that in one area we want to accelerate development, and here we want to develop at a slower pace. We want to run the breeder reactor at a faster pace, and this program in magnetic fusion is at a slower pace.

In your estimation, if we go back at least to the 1982 budget, would we be able to fund these other projects at a little faster pace?

Dr. CLARKE. Yes, sir. We would. To the extent that we could.

Mr. VOLKMER. Yes.

Dr. CLARKE. It would certainly not be enough money to fund all of the projects that we are talking about.

Mr. VOLKMER. No.

Thank you very much, Madam Chairman.

Mrs. BOUQUARD. Thank you very much, Mr. Volkmer.

Earlier in my opening statement, I referred to the Magnetic Fusion Energy Engineering Act of 1980 which sets a goal-oriented schedule. It certainly disturbs me that we are modifying these goals after the directives of the Congress called for a 25-percent real annual increase in the funding. This is what distresses me so about this program.

What level of funding in the various program areas would have been required in the fiscal year 1983 request to maintain the aggressive program pace envisioned by the Magnetic Fusion Energy Engineering Act?

Dr. CLARKE. Basically, what would be required to accomplish the purposes of that act——

Mrs. BOUQUARD. Yes, sir.

Dr. CLARKE. This would include the restoration of the projects that we have had to defer because they provide the basic information on which we would advance the basic scientific information.

In addition to that, we would have to start the process of developing additional fusion technologies, and we would have to begin the establishment of a fusion engineering device project of some sort.

The amount of money required for the enhancement of technologies and the preparation for the fusion engineering device isn't a great deal of money in the first year. Most of the money that would be required to enter upon a program to fulfill the purposes the act would go for the continuation of existing technology development such as those magnetic field coils that I showed you, the tritium systems assembly, and nuclear technology.

In other words, it is the enhancement of things that are already existing in the program.

Mrs. BOUQUARD. Dr. Clarke, I can assure you that it is the will of this subcommittee that we move ahead with the engineering phase.

Dr. CLARKE. Madam Chairman, I assure you that we are doing everything that we can within the funds available to us.

Mrs. **BOUQUARD**. How much more money would be involved to go ahead with the schedule as we outlined 2 years ago?

Dr. **CLARKE**. In terms of the plans that we have made—the planning studies that we have made of what would be required—we are talking on the order of $100 million over and above the proposed budget.

Mrs. **BOUQUARD**. And what timeframe are you talking about, Dr. Clarke?

Dr. **CLARKE**. This would be an amount of money that would restore the basic projects that are part of the core program and begin the engineering technology development over a year.

Mrs. **BOUQUARD**. How much more cost will be incurred as a result of the slippage of MFTF-B? Have you looked at this?

Dr. **CLARKE**. Well, yes, we have under various scenarios. It is quite clear that when projects are postponed there are increased costs incurred. It is an unfortunate consequence of the present budget constraints that we will have to incur those costs in the future.

Mrs. **BOUQUARD**. Do you agree with Secretary Edwards and the Office of Science and Technology Policy that fusion energy will not be available for 20 or 30 years? What is your assessment of fusion energy?

Dr. **CLARKE**. Dr. Trivelpiece answered that question the other day at the Senate hearing, and I think that I agree with his response. He said that any energy technology will require 20 to 50 years to make a significant impact on the energy supply of the Nation. I think that may well be what the Secretary was referring to.

Mrs. **BOUQUARD**. But I am asking when you think fusion energy will be available.

Dr. **CLARKE**. Our position is that with sufficient backing, the basic principles of fusion would be available to begin practical application within approximately 20 years. It may well be an additional 30 years before that energy technology has a significant impact on the energy supply of the Nation.

Mrs. **BOUQUARD**. Do you have any doubts that we are not ready to move ahead into a significant engineering development phase? If so, upon what are these doubts based?

Dr. **CLARKE**. All of the studies that we have done, and all of the scientific results that we gained in the program over the past year since we testified before your committee, indicate there is no technical or scientific obstacles in moving ahead. What we have here is simply a question of not having sufficient budgetary priority within the overall Federal Government to move ahead with the program.

Mrs. **BOUQUARD**. But would you not agree that it is easier to accelerate a scientific program than a program where there has been sufficient engineering work done?

Dr. **CLARKE**. I don't think that it is a question of science versus technology. I think it is a question of priority of developing a new energy technology versus the other priorities that the Government has to address.

Mrs. **BOUQUARD**. Another area that is of great concern to me is the possible shortages of scientists and engineers to develop new energy technologies.

The Magnetic Fusion Energy Engineering Act required an assessment of the supply of scientists and engineers necessary to carry out the purposes of this act.

Would you care to comment on this assessment, Dr. Trivelpiece?

Dr. TRIVELPIECE. I think Dr. Clarke is in a better position to answer that question. He did carry out a study. He was responsible for a study, both for the nuclear engineering programs in the United States, and also he was involved in the Department study which was mandated under the act with regard to assessing the need for scientific manpower.

I think I would prefer to let him answer based on his direct experience with that.

Mrs. BOUQUARD. Please proceed, Dr. Clarke.

Dr. CLARKE. I would be very pleased to answer that because I think I have happy news for you.

We have assessed the need for fusion manpower in both the scientific and engineering aspects of fusion, and we find that there really is no constraint to the expansion of the fusion program or any expansion that we could envision over the next 10 years due to manpower.

We are presently producing enough scientific personnel. The total number of engineering personnel that we would require for even the most vigorous expansion of the fusion program could be supplied through the industries that would be involved in carrying out most of that technology development and construction work.

Mrs. BOUQUARD. Dr. Clarke, in a number of places in your testimony you referred to the fusion engineering device [FED]. Would you summarize the current and the planned activities that are really addressing the FED? When do we plan to initiate significant design studies and engineering of the device?

Dr. CLARKE. Well, as I indicated in my oral testimony, we have completed a first preconceptual design of the FED. We know from the work that we have done that it is not an optimal design, that there is room for considerable improvement as our scientific knowledge increases.

Our present plans are to continue the evolution of that program so that at the point when the country feels ready to proceed with such a project, we will have an optimized cost-effective system.

Specifically, we are looking at those critical engineering and scientific problems which have the greatest cost consequences or reduce the performance of the device.

We are also looking at how the device can be modified based on recent scientific advances such as the ability to drive currents with radio frequency fields which was demonstrated this year at Princeton.

Finally, we are looking at alternative systems that might form the basis for a more cost-effective FED such as the tandem mirror system. We think that these studies will take us approximately 2 years. This year we are doing a preconceptual design of a mirror-based FED. On the tokamak side, we are looking at critical issues associated with carrying forward the present tokamak system. Next year, we will be integrating the solutions to those critical problems areas in the tokamak side, and we will be looking at critical issues in the mirror side.

By the end of 2 years, we should have sufficient information on both the tokamak-based and the mirror-based FED to make a rational assessment of their relative benefits and cost.

Mrs. **Bouquard**. Mr. Volkmer? Do you have any further questions?

Mr. **Volkmer**. No; I have no further questions.

Mrs. **Bouquard**. It is our understanding that the OHTE device under development by the General Atomic Co. is a combination of a reversed field pinch and stellarator. It is also our understanding that INESCO is developing, with private capital, a small tokamak device. Are there any synergisms between the DOE and GA and INESCO programs that can help advance the generic U.S. fusion program?

Dr. **Clarke**. Well, yes, Mrs. Bouquard, I think there is. Both INESCO and the OHTE device at General Atomic are being developed solely on private risk capital.

With regard to the OHTE device, there are great similarities between the OHTE and the reversed-field pinch which is under development at Los Alamos. There is a direct interaction between the scientific personnels on the private-sector side in OHTE and in the National laboratory side at Los Alamos. Data is being exchanged.

With respect to the INESCO program, our program produced the basic physical insights on which that development project is based and we are presently providing INESCO with computer codes which were developed in the Federal program to aid them in their development through the computer code center at Argonne National Laboratory.

I would like to say that we applaud both of these efforts because the basic purpose of the Federal program is to provide a data base on which industrial entrepreneurs can use to develop practical products. I think the OHTE and the INESCO efforts represent the first such indications of people striking out from the data base that we have provided to try to develop these products.

Mrs. **Bouquard**. We are very concerned about the reduced funding level for the EBT-P in the fiscal year 1983 budget. What is the current status of the EBT-P, Dr. Clarke?

Dr. **Clarke**. We will have committed approximately $30 million on that project by the end of fiscal year 1982 including about $21 million on construction.

Mrs. **Bouquard**. That is $21 million of construction?

Dr. **Clarke**. Of construction funds and a total of $13 million of operating funds through the end of fiscal 1983.

Mrs. **Bouquard**. Through 1983.

Dr. **Clarke**. We are phasing the spending of those funds to keep the basic EBT design team together because, as I indicated before, we do not have enough money within the proposed fiscal year 1983 budget to begin construction of that project. We are trying to keep the essential core design team together to allow them to finish the R&D and the design, so that we would have the wherewithal to begin the construction if we can provide sufficient funds within the 1984 budget.

Mrs. **Bouquard**. How much more funding do we need to maintain the previous planned start of the experimental operations in late fiscal year 1983?

Dr. **Clarke**. It would require approximately an additional $20 to $25 million to proceed with the optimum project schedule.

Mrs. **Bouquard**. How much is the projected delay going to increase the cost of EBT-P, Dr. Clarke?

Dr. **Clarke**. I am sorry. I cannot give you a direct answer to that. It very much depends on how much funding can be provided in the outyear budgets. You can have any answer from $10 to $50 million depending on how long the project is delayed.

Mrs. **Bouquard**. Well, it seems to me that by our delays and by our cutback in this program, we are really turning off the sort of industrial participation that we were trying to achieve.

Dr. **Clarke**. It is a great disappointment to us that we are not able to proceed within the present budget with the construction project. The McDonnell Douglas Corp. is doing a superb job in designing and doing experimental work in support of that EBT-P project. I think that is a very good illustration of the power of industrial involvement in fusion.

We will do everything in our power to preserve the project, but we are constrained by the overall moneys allocated to the program.

Mrs. **Bouquard**. If you recall, the Department failed to comply with the Magnetic Fusion Energy Engineering Act's requirement that a comprehensive program management plan be transmitted to the Congress by January 1, 1982.

What is the current status of the plan? Where is it? What is the Department doing to insure that this plan is indeed going to be prepared, Dr. Trivelpiece?

Dr. **Trivelpiece**. The Secretary has signed a letter which is being transmitted to Mr. Fuqua to indicate we recognize the need to prepare a plan. We did explain in earlier correspondence that the budgetary situation was making it difficult to prepare a plan on exactly the schedule which had been originally anticipated. We do plan to submit a full report in October. In the meantime, we will submit an interim report in about 2 months given your——

Mrs. **Bouquard**. An interim report in 2 months?

Dr. **Trivelpiece**. Yes, around the end of May. Given your interest and concerns, certainly we would be happy to have Dr. Clarke or other members of the fusion program provide direct briefings on the status of the planning activities that are taking place.

Mrs. **Bouquard**. Well, that certainly would be welcome.

I would now like to welcome my colleague, the Honorable Sid Morrison from the State of Washington to our committee. He represents the area that includes Hanford, Wash., where much of our research is being done.

Sid, we welcome you and we look forward to your input into our hearings this morning.

STATEMENT OF HON. SID MORRISON, A MEMBER OF CONGRESS FROM THE STATE OF WASHINGTON

Mr. **Morrison**. Thank you. Thank you, Madam Chairman. Probably for a nonmember of this committee, I am spending more time with you than I deserve. I appreciate this opportunity.

Mrs. **Bouquard**. We assure you that your presence is most welcome.

Mr. MORRISON. Thank you.

I would like to join this subcommittee in its strong support for magnetic fusion. Under the leadership of my predecessor, Mike McCormack, the United States took the leadership role in the development of fusion energy.

Today I feel that we stand at the crossroads of timely development of a potentially limitless source of energy or retrenchment into the past.

In order for the fusion program to proceed in an orderly fashion, the engineering and physics research must proceed hand-in-hand.

The linchpin of this program is the Fusion Materials Irradiation Test facility. It was a major system authorized in fiscal year 1978 to provide the only practical capability in the world to produce a fusion-like neutron environment for development of fusion materials.

The facility is to be located at the 570-square-mile Hanford Nuclear Reservation in the southeast corner of my district. Its location at Hanford will allow it to take advantage of the Hanford Engineering and Development Laboratory's expertise and success in materials development for the liquid metal fast breeder reactor program.

By October of this year, Madam Chairman, $80 million will have been spent on research and development, design, and procurement. The major development tasks are completed, and all systems designs are over 50 percent complete with facility design 100 percent complete.

The project is ready to initiate construction with an estimated completion date of 44 months after initiation, including equipment installation and startup.

There has been great interest shown by the Japanese in entering into a joint effort on the fusion material test facility. To zero the project now, which is included in the budget in front of us, would foreclose that option of cooperation.

I would like to include as part of the record the attached summary of a trip taken by the FMIT project managers to Japan to meet with representatives from the Japanese Atomic Energy Research Institute. That institute has indicated the desire to participate in the FMIT project. Informally, the fraction used in the discussions was 20 to 30 percent which translates into $40 to $50 million.

Unfortunately, this joint funding potential doesn't translate into immediate cash which is our current problem. Any cooperative effort will require a Department of Energy commitment and management plan for fusion materials testing.

Only when there is a plan in place, can we proceed to deal with cautious investors like the Japanese.

I would hope the subcommittee would consider this information in a favorable light. I recognize the constraint which budgetary pressures force, but postponing the project will postpone at least year to year, the date fusion can be counted on to mitigate the many and increasing intractable problems of our current energy situation.

I might add that if it is deferred, that we lose the collection of people that we have at the Hanford facility already in place to work on this project, maybe never to be able to assemble them again.

As I mentioned, elimination of the funds for FMIT will send a signal to those who would be willing to join in this effort that the United States is not committed to solving our long-range energy problems.

Thank you, Madam Chairman, for the privilege of making this statement.

Mrs. BOUQUARD. Thank you very much, Congressman.

Mr. MORRISON. I would submit this report on the visitation with the Japanese.

Mrs. BOUQUARD. Without objection, it will be made a part of the record.

[Material supplied follows:]

Hanford Engineering Development Laboratory

From FMIT Project
Phone 376-4304 W/E-15
Date February 2, 1982
Subject SUMMARY TRIP REPORT

To E. W. Pottmeyer, Jr.

cc:

EA Evans	W/C-23
DE Simpson	W/B-63
HH Yoshikawa	W/C-44
JH Anttonen	DOE/RL
GM Chenevert	DOE/RL
SW Luke	DOE/HQ
M Roberts	DOE/HQ
TC Reuther	DOE/HQ
ALT/File-LB	

Dr. Herbert Yoshikawa, Manager, Technology, and Dr. LaMar Trego, Manager, FMIT Project, visited representatives of the Japanese Atomic Energy Research Institute (JAERI) at JAERI headquarters in Tokyo and at the Tokai research establishment during the week of January 25-29, 1982. The purposes of the trip were to provide current information on the status and technical progress of the FMIT and to discuss various possible modes of cooperation that might be developed for the project.

Key JAERI personnel with whom we had discussions were:

S. Mori	Director
Y. Iso	Center Director, Fusion Research & Development Center
Y. Obata	Head, Division of Thermonuclear Fusion Research
J. Shimokawa	Head, Division of Nuclear Fuel Research
S. Ikari	Chief, Office of Fusion Program
K. Yoshizawa	Chief, Office of International Affairs
Y. Hamaguchi	Deputy Head, Division of Physics

We also had a short meeting with Mr. Kagimoto, Director, Technology Promotion Division, Science & Technology Agency (STA), and Mr. Takeda, Deputy Director.

The discussions were extremely friendly and cordial. A desire to participate in the FMIT project was consistently expressed by JAERI personnel. A record of discussions is attached with the third and fourth paragraphs containing the key statements.

Conclusions and Observations

The desire of the JAERI to participate in the FMIT project was expressed repeatedly at all levels. Informally the fraction used was 20-30% which translates into $40-$50M dollars. The funding, of course, would be spread over a few years and could not all be provided initially. They expressed interest in providing some funding in FY1983 to assist with the lithium and accelerator test programs. We are convinced that attainment of a cooperative agreement is possible. We recommend that action be taken to initiate formal discussions during the visit of JAERI personnel to ORNL and HEDL at the end of February.

A complete trip report will be written and distributed in the near future.

A. LaMar Trego
A. LaMar Trego, Manager
FMIT Project

eb

Attachment: 1

RECORD OF DISCUSSION ON JAPAN-UNITED STATES PARTICIPATION IN THE FUSION MATERIALS IRRADIATION TEST FACILITY (FMIT)

JAERI-Tokai, Japan
January 26-28, 1982

Discussions between representatives of the Japan Atomic Energy Research Institute (JAERI) and the Hanford Engineering Development Laboratory (HEDL) related to potential joint participation in the construction and utilization of FMIT took place at Tokai, Japan, on January 26-28, 1982. The meeting followed the agenda shown as Attachment 1. Members of the HEDL and JAERI delegations are listed in Attachment 2.

Material describing the current status and recent progress on the FMIT facility was presented by HEDL representatives and is included as Attachment 3. In summary, the FMIT building and support services systems designs are complete and major equipment systems designs are progressing toward completion. The accelerator radio-frequency power, radio-frequency quadrupole, drift tubes, injector, lithium heat exchanger, and main lithium pump are in fabrication or testing. Testing of the accelerator, lithium target and lithium system components have continued with favorable results. The project is ready for the start of construction and procurement as soon as funding becomes available.

The JAERI are convinced of the critical need for a facility having the capabilities of FMIT in the research and development of materials for fusion applications. JAERI desires to have a significant fraction of the FMIT testing capacity available to them to carry out their fusion materials program. JAERI believes that a cooperative program on FMIT represents the fastest and least costly approach to acquire those testing capabilities.

In recognition of the importance of the FMIT program to JAERI, assignment of a JAERI scientist, Dr. Katsuta, to HEDL to participate in the FMIT design and development is scheduled for March. Additional phases of cooperation which could be considered are;

Phase 1. Initiate a wider collaboration which would include a joint program to complete lithium, target and accelerator system testing. This phase is dependent upon continuation of the U.S. program in 1983,

Phase 2. If it is decided to proceed with construction the JAERI and HEDL would consider recommending to their governments that a joint program of construction and procurement be conducted,

Phase 3. After completion of the facility initiate a joint program of facility operation and neutron irradiation.

H.H. Yoshikawa
H. H. Yoshikawa

J. Shimokawa
J. Shimokawa

Mrs. **Bouquard**. We would like at this time to recognize the ranking Republican on this subcommittee, the Honorable Manuel Lujan from New Mexico. Welcome, Mr. Lujan.

Mr. **Lujan**. Thank you, Madam Chairman. I do have an opening statement for which I will ask unanimous consent to include it in the record. I would just like to take a moment to say that I have been a supporter of the fusion program all along. I voted for the Magnetic Fusion Energy Engineering Act. I am just sorry that it appears that we will be postponing the device for a while.

One of the concerns has been how fast to move on it. The whole fusion program will be constrained by the budget as it is. I would have hoped that we could move faster, but it appears that we will have to take it a little more slowly.

Nevertheless, I will be interested in the testimony of the witnesses today, and I hope that we will do the best that we can as far as the program is concerned within the confines that have been laid out for us.

Thank you.

Opening Statement of Hon. Manuel Lujan, Jr., Department of Energy Fiscal Year 1983 Authorization Hearings—Magnetic Fusion Programs, March 23, 1982

Thank you, Madam Chairman. As you know, I have been a strong supporter of the magnetic fusion program. In 1980, I voted for the Magnetic Fusion Engineering Act.

Now that the Federal budget restrictions force us to postone the engineering device for a few years, it looks to me like we have an opportunity to examine the fusion program and to determine the best concept before we commit to large scale construction projects. We may otherwise narrow our choices for the best reactor option too early, by building an engineering device before the verdict was in from the physics experiments.

As with any form of energy research and development, I believe it is best to optimize the amount of international cooperative efforts. For example, I have been impressed with the tremendous progress the Japanese have recently made. There has been an ongoing cooperative effort between the United States and the Japanese. A significant difference between the United States and Japanese fusion programs is the degree of industrial involvement in the design and fabrication of Japanese fusion machines This high level of industrial involvement in government projects gives Japanese industry a leg up, should fusion ever go commercial. I believe the more industry involvement in energy research and development—be it fusion, fission, solar, geothermal, or wind—the better.

I am looking forward to discussing with the Department of Energy witnesses today, the future directions of the fusion program.

Thank you, Madam Chairman.

Mrs. **Bouquard**. Thank you very much, Mr. Lujan. Do you have any questions? Would you like for your questions to be submitted for the record?

Mr. **Lujan**. I have no questions right now, Madam Chairman.

Mrs. **Bouquard**. Thank you very much.

Mr. Volkmer?

Mr. **Volkmer**. Yes, Madam Chairman, I would like to ask Dr. Clarke, what do you think about the statement from a panel of experts convened by EPRI which concluded that fusion-fission hybrids appear to be the most practical first application of fusion; that it would be techologically easier and potentially more competitive energy option than fusion electricity generation?

What do you think about that?

Dr. **Clarke**. Well, Mr. Volkmer, I have read the EPRI report. I think it was a very thorough job. It was, of course, a recommendation to EPRI. Their basic conclusion was that the fusion-fission hybrid would be a technology which would serve to preserve the utility of the billions dollars of utility investment in light water reactors through the next century.

The Department's position on the hybrid is that if we are successful in developing a fusion neutron source, those neutrons could be used for a number of purposes. One of the purposes would be as indicated by this EPRI committee, the breeding of fissile fuel.

They concluded that under appropriate circumstances, one could support the 20 to 50 light water reactors from the fuel produced from a single suppressed fission hybrid fuel sources.

Now, if that could be developed, it would certainly make a very attractive fuel source for the utilities.

However, the basic problems in fusion are to produce those neutrons in the first place. That is what our program is directed at.

We have considered the use of the fusion engineering device for the testing of hybrid modules. We have considered in our engineering development plans the use of fission reactors to develop hybrid modules. These things are all possible if we have the basic neutron source that underlies that application.

Mr. **Volkmer**. How long do you estimate that it will be before we have scientific feasibility in magnetic fusion?

Dr. **Clarke**. Well, having worked in this field for as long as I have, I am personally convinced that we will achieve scientific feasibility, but the demonstration is presently scheduled for 1985 with the TFTR facility at Princeton.

Mr. **Volkmer**. I have no other questions, Madam Chairman.

Mrs. **Bouquard**. Thank you, Mr. Volkmer.

Mr. Lujan?

Mr. **Lujan**. Yes, Madam Chairman. Something has come to mind.

DOE's 1983 request describes outstanding advances at Los Alamos with the ZT-40 reversed-field-pinch device. However, they tell me that in order to fully capitalize on these advances, we need a new power supply there. Last year Mr. Kintner said that those would be taken care of, but there is nothing in the 1983 budget which indicates that they will be funded. How are we going to handle that?

Dr. **Clarke**. Well, clearly in the long run, we will have to provide some money. The situation with respect to the ZT-40 is as you indicate. The experiment has been very successful. It has made some fundamental advances in reversed-field-pinch operation. However, the machine has not reached its full potential even with the present power supplies. We are working with the Los Alamos National Laboratory to decide what is the most appropriate and the most economical form for their future power supply.

Mr. **Lujan**. My understanding is that there will have to be some modifications to the machine as we move on, but even then we need that new power supply. Eventually we could authorize a new power supply. Am I correct in what I am saying?

Dr. **Clarke**. That is correct, sir. We are presently trying to evaluate whether or not we can get by with a used power supply from a utility or whether we will have to go for a new supply, and if we have to go for a new supply, exactly what type will it be.

Once those technical considerations are completed, then we would have to make our decisions as to an appeal for funding.

Mr. LUJAN. Would it help you any for this committee to line item money for the modification and for the power supply? We could do it in some modest amount. I think the figure we are talking about would be $2 or $3 million, something like that, but it would give you the authority if it was a line item. I am trying to be helpful. [Laughter.]

Dr. CLARKE. Yes, sir. I appreciate your help.

Mr. LUJAN. Why don't you just stop at "Yes, sir." [Laughter.]

Or just at the "Yes?" [Laughter.]

Would it be helpful though, seriously?

Dr. CLARKE. We presently have money in the proposed 1983 budget for general plant projects at Los Alamos. I think the most immediate need for funding with respect to this power supply is site preparation. If it is decided to move forward with that power supply, I think we have sufficient power resources to do the basic preparation.

Mr. LUJAN. The first part of your answer was much better. Do you mean that you have money for the upgrading of the present device?

Dr. CLARKE. No, sir. We have general plant funding, general improvements of a minor nature.

Mr. LUJAN. You are talking about the power source now?

Dr. CLARKE. Yes. I am talking about the power source. The generator, either used or new, would have to fit into some sort of facility. We have money to begin preparation of that site—foundations and work like that. This is a long project. It will require a lot of analysis to decide exactly how much it will cost and what is the most economical way to enhance their power supply.

Mr. LUJAN. Where is that money coming from? Do you mean it is coming from the overall fusion program? Some of us are concerned that the fusion dollars are limited to begin with. You know, we are saying that we will have to steal from somebody else.

Dr. CLARKE. Yes. Within the overall fiscal year 1983 request, we have funds requested for general plant projects. I think that the total is roughly $6 million.

Mr. MAYHEW. Yes.

Dr. CLARKE. It is about $6 million. Some of that money is allocated for physical improvements at Los Alamos.

Mr. LUJAN. With that allocation you could begin on the facility for the powerplant.

Dr. CLARKE. Yes, sir. We could begin site preparation.

Mr. LUJAN. Now, what about the money we would need for upgrading the present machine? Do you have some money there?

Dr. CLARKE. We have money allocated. I would have to check the details of exactly whether we have covered facility improvements for that machine. I am not sure of the answer.

Mr. LUJAN. On another subject: EBT. You already said that the ZT-40 is a successful operation. EBT is being zeroed out. Is that correct? What kind of followup do we have there?

Dr. CLARKE. We have a moderate amount of money for the EBT project included in this budget request. That money, together with the authorization for fiscal year 1982, will allow us to maintain the project team and the continuation of the research in support of the project through fiscal 1983.

I indicated that the decision as to what to do with respect to project construction is something that depends on the ability to fund it in the fiscal year 1984 budget.

Mr. LUJAN. Thank you.

Mrs. BOUQUARD. Thank you very much, Mr. Lujan.

If there are no further questions, I would like to thank our witnesses for being with us today and all of you that are here today to listen to our hearings.

Mr. Morrison, do you have further questions?

Mr. MORRISON. I have perhaps just one question, if I might, Madam Chairman.

Mrs. BOUQUARD. Please proceed.

Mr. MORRISON. Dr. Clarke, on page 22 of your testimony, the only mention of the fusion testing program which I included in my statement appears, indicating that it will cease at the end of the fiscal year 1982. Based on the overall stretch out of the fusion program schedule, there is a reduced urgency to provide for this materials test facility at this time.

Do you have any timeframe in mind for a completion of the materials testing portion of the fusion program?

Dr. CLARKE. Yes, sir. As you indicated in your statement, we are presently making approaches to the European Community and to the Japanese Government to try and obtain international support for this project. We consider the FMIT project to be of fundamental importance to fusion in the long term.

It is our estimate that it would take approximately 2 years of negotiation, given the budgetary process in Europe and Japan, to obtain significant support for the project.

We will try to maintain a core technical team at Hanford during this period to allow us to conduct the technical negotiations which would lead to this foreign support.

Therefore, what we are trying to accomplish is to restart that project within the next 2 years, presuming that we get substantial foreign support.

Mr. MORRISON. Do you think it will improve our chances of getting that foreign support going together if we showed a greater commitment to that through a construction—proceeding with a construction?

You know, there is a beautiful big hole in the ground there now with Mike McCormack's name on a sign right beside it. A number of us would like to proceed with that construction as the best way of showing, as I mentioned, the very cautious investors that we are dealing with that there is a very real commitment on the part of the U.S. Government to have this be a top priority part of the fusion program.

Dr. TRIVELPIECE. If I may, Congressman, I was in Japan. It seems like several weeks ago, but in fact, it was only a week ago. The Japanese are interested in joining us in this project in an appropriate manner. I think that they would like to see us proceed with the construction and then join us in the operating phase; however, we are engaging in some discussions with them at the moment to determine their possible interest in sharing the basic facility construction costs with us. I believe as you indicated that it is correct. They are cautious investors, and we are moving carefully to determine their possible interest.

Mr. MORRISON. Thank you very much.

Mrs. BOUQUARD. Mr. Lujan.

Mr. LUJAN. I am concerned about when we finally begin producing electricity from fusion. A big problem that we are having, of course, right now with nuclear reactors is the expense in building these gigantic machines. As I see the fusion program developing, we are not really addressing that particular issue. What I am leading to is most of the funding—as a matter of fact, 90 percent—is for research on the big machines—and about 5 percent of the funding is for research is on the compact machines.

It seems to me like more of the resources ought to be allocated to the compact machines—because of what we have learned from the fission program—that the high construction costs are going to be great stumbling blocks.

I don't know that that is so much of a question. It is a concern, but if you would like to comment——

Dr. TRIVELPIECE. I would like to comment. At the beginning of the session, Madam Chairman asked me about the OMB involvement in our activities. I think that part of the debate which took place at the time that this was under concern was whether or not an appropriate balance existed between construction and operating funds.

We did make adjustments to the program to try to bring it into what we felt was better balance consistent with the overall Department's programs, and we reflected the need to have activities such as you are talking about supported, particularly looking forward, as we understood the situation from the administration point of view, that we were not likely to see growing budgets in the next few years. Did we have a sound balanced program? We have made adjustments that we believe are appropriate within the constraints that we have had to live with.

Mr. LUJAN. To shift some funding out of the big machine—would that upset the program terribly? It would upset the ones that have big machines, obviously. However, in terms of program results, shifting some of the expenditure from tokamak, and that sort of thing, into the smaller machines may be desirable.

Dr. TRIVELPIECE. Each of these adjustments is a wrenching experience. To try to develop an appropriate compromise is difficult. We have tried to do so, and we are presenting a program and a budget that we believe is the best compromise that we can bring under the circumstances.

Mr. LUJAN. That is because of the limited total funds. You have then gone ahead with those programs that seemed to be further advanced or that have the largest investment. You have continued to invest in these programs—and I don't mean this derogatorily—and what funding was left over, then was assigned to the small machine program?

Dr. TRIVELPIECE. Well, from the point of view of the Department as a whole, we have had to make this adjustment in several areas, by reducing the emphasis on construction projects in order to maintain and take advantage of facilities already in existence. This process has been a general strategy that has been applied in a number of places. It has been a wrenching experience both on us and I think on the people in the field who are influenced by the consequences of that.

The fusion program has had to share in the same kind of activity that the Department as a whole has had to engage in.

Mr. LUJAN. Did DOE ask for more funds in the fusion program than finally came out review by OMB?

Dr. TRIVELPIECE. No. The OMB did return a passback to us that was equal to our request.

Mr. LUJAN. Did you not request more for the smaller machine than the amount that is included now?

Dr. TRIVELPIECE. No, sir.

Mr. LUJAN. You do not think that it could be used, or was there some barrier there?

Dr. TRIVELPIECE. Well, there was a constraint that the Department as a whole had to face in meeting its budget guidance. It was within that overall budget guidance that we arrived at a number for the fusion program. When that was transmitted to OMB, it was returned to us at the requested level.

Mr. LUJAN. But had you been able——

Dr. TRIVELPIECE. It was very strong support as we regarded it.

Mr. LUJAN. But had you not had those constraints or that barrier on top, you could have requested more funds in the small machine program.

Dr. TRIVELPIECE. That is a hypothetical question. I would have to give you a hypothetical answer. I don't have a good answer for it.

Mr. LUJAN. How about a hypothetical yes. [Laughter.]

Dr. TRIVELPIECE. All right.

Mr. LUJAN. Thank you, Madam Chairman.

Mrs. BOUQUARD. Thank you very much, Mr. Lujan. Are there any further questions?

[No response.]

Mrs. BOUQUARD. If not, I would again like to thank our distinguished witnesses today. Thank you for your testimony. I would also like to thank all of you who are in attendance today.

The subcommittee will meet again in the morning at 9 o'clock. We will be here in room 2325, to hear from our non-Government witnesses on magnetic fusion.

If there are no further comments, we stand adjourned.

[Whereupon, at 10:28 a.m., the subcommittee recessed, to reconvene on Wednesday, Mar. 24, 1982, at 9 a.m.]

[App. I, questions and answers submitted for the record and app. II, additional material submitted for the record, follow:]

APPENDIX I

QUESTIONS AND ANSWERS SUBMITTED FOR THE RECORD

DON FUQUA, FLA., CHAIRMAN

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RT GORE, JR., TENN.
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BILL NELSON, FLA.
STANLEY N. LUNDINE, N.Y.
ALLEN E. ERTEL, PA.
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RALPH M. HALL, TEX.
DAVE MCCURDY, OKLA.
MERVYN M. DYMALLY, CALIF.

LARRY WINN, JR., KANS.
BARRY M. GOLDWATER, JR., CALIF.
HAMILTON FISH, JR., N.Y.
MANUEL LUJAN, JR., N. MEX.
HAROLD C. HOLLENBECK, N.J.
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WILLIAM CARNEY, N.Y.
MARGARET M. HECKLER, MASS.
F. JAMES SENSENBRENNER, WIS.
VIN WEBER, MINN.
JUDD GREGG, N.H.
RAYMOND J. MCGRATH, N.Y.
JOE SKEEN, N. MEX.
CLAUDINE SCHNEIDER, R.I.
JIM DUNN, MICH.
BILL LOWERY, CALIF.

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THOMAS P. GRUMBLY

GERALD E. JENKS
MINORITY STAFF DIRECTOR

December 29, 1981

Dr. Alvin Trivelpiece
Director, Office of Energy Research
Department of Energy
Washington, DC 20585

Dear Dr. Trivelpiece:

We appreciate the time you and your staff spent with us on December 16, 1981 and the useful information provided in your program briefing on DOE's magnetic fusion energy program.

As we discussed at that time, Subcommittee staff have developed additional questions pursuant to the briefing. I have attached a copy of these questions and request that this additional information be made available to us by January 15, 1982.

Thank you for your assistance.

Sincerely,

John V. Dugan, Jr./cg

JOHN V. DUGAN, JR.
Staff Director
Subcommittee on Energy Research
and Production

JVD:Gma
Attachment

December 29, 1981

ADDITIONAL QUESTIONS TO THE
DEPARTMENT OF ENERGY

MAGNETIC FUSION ENERGY PROGRAM

1. The November 1981 report of the Research and Development Panel of the Energy Research Advisory Board entitled Federal Energy R&D Priorities, transmitted to Deputy Secretary Davis on December 4, 1981 by ERAB Chairman Roddis found that small reductions in magnetic fusion program funding can be made relative to the President's FY'82 budget request. Please comment on this finding.

2. The aforementioned report also recommends "that an enhanced effort to examine the use of fusion for the breeding of nuclear fuels deserves consideration."

(a) Do you agree with this recommendation?

(b) What are OFE's current activities in this area?

(c) What efforts are planned in this area and what is the projected funding?

3. On page 2 of the DOE report DOE/TIC-11600 entitled The Fusion Engineering Device: Executive Summary, it is stated: "The selection of the tokamak for FED should not and does predestine the course of commercial development. The problems to be solved for FED are in large part generic to other approaches, and other promising alternatives to the tokamak approach will be pursued to the extent needed to ascertain their relative merit." Delineate in detail the "problems to be solved for FED" that "are in large part generic to other approaches," as well as those that are not.

4. Also on page 2, it is stated that the approach to the implementation of a formal U.S. policy on fusion research "was arrived at through the diverse talents and skills of laboratories, universities, and industries in a national effort to utilize the unique skills of each organization for the benefit of a national fusion program." What are the skills that are unique to each organization which have significant roles in the various subactivities?

5. What are the detailed FY'80, FY'81, FY'82, and FY'83 funding levels and program milestones for the following subactivities of the Applied Plasma Physics activity: 1) Experimental Plasma Research, 2) Advanced Fusion Concepts, 3) Computer Services & Technology, and 4) Fusion Plasma Theory? Please provide justification of how each of the major tasks/projects carried out in these subactivities support the stated subactivity objectives. How are these elements being realigned to support a focused physics program?

6. What are the detailed FY'80, FY'81, FY'82, and FY'83 funding levels for advanced fuel assessment? What was accomplished in FY'80 and FY'81 and what are the planned accomplishments for FY'82 and FY'83? Please

provide a detailed justification of how this program and the efforts funded by this program support the stated objectives of the Advanced Fusion Concepts subactivity?

7. Has any analysis been done on the possibility and/or feasibility of establishing at least nominal user fees for the MFE Computer Network? If not, why not? How many users during the last 3 fiscal years were not funded by OFE when they used the Network?

8. For each current or planned facility supported and/or operated by OFE (e.g., Alcator C, ISX, PLT, TARA, etc.), please provide a detailed explanation of the uniqueness of each machine and how each will be used to provide the answers needed to further the FED design effort.

9. In the December 16 briefing, eight fusion physics issues were delineated (heating, fueling, MHD equilibrium and stability, etc.). Which of these are critical to the design, construction, and operation of the FED? What OFE activities are underway or planned to address each of the critical issues? Identify these by subactivity, e.g., D&T, APP, etc.

10. Using the current drive achievements outlined in the 12/16/81 briefing, provide estimates for the durations of time and costs involved in performing the studies that led to the PLT and Versator results. Include data from the relevant work of prior years.

11. Rank the technology accomplishments delineated in the 12/16/81 briefing charts according to their importance and criticality to the goal of achieving an EPR.

12. Clarify the role of the FED as a major focus of the magnetic fusion energy program.

A. How will the applied plasma physics activities support the FED design, fabrication and implementation?

B. Which of the present generation devices support the FED project by providing critical design data?

C. How will these activities be coordinated from a management viewpoint?

13. To assist the Committee in gaining a clearer understanding of the interrelationships of the various projects within MFE subactivities, the following information is requested.

A. Using the program flow chart shown on Page IV-5 (copy enclosed) of the January 1980 MFE program summary document as a guide, develop a critical path flow chart showing in more detail the critical tasks and interrelationships among the several key projects within each subactivity.

FACILITY QUESTIONS - TFTR

14. In a meeting in January, 1981, we were told that the TFTR was scheduled for operation (First Plasma) in August, 1982. Later this date was slipped to December, 1932. Is that date still valid? If not, how can it be restored?

15. The TFTR was to become operational in 2 fundamental steps: Step 1 was to use hydrogen; step 2 operations was to be full D-T. As you know, scientific breakeven cannot be accomplished without D-T and the D-T operations were scheduled to follow the hydrogen by 2 years This would mean D-T operations will occur around December 1984. Is this date still firm? Why do current plans call for 2 years of hydrogen operation?

16. When will three neutral beams be operational?

17. Have the upper poloidal field coils been delivered?

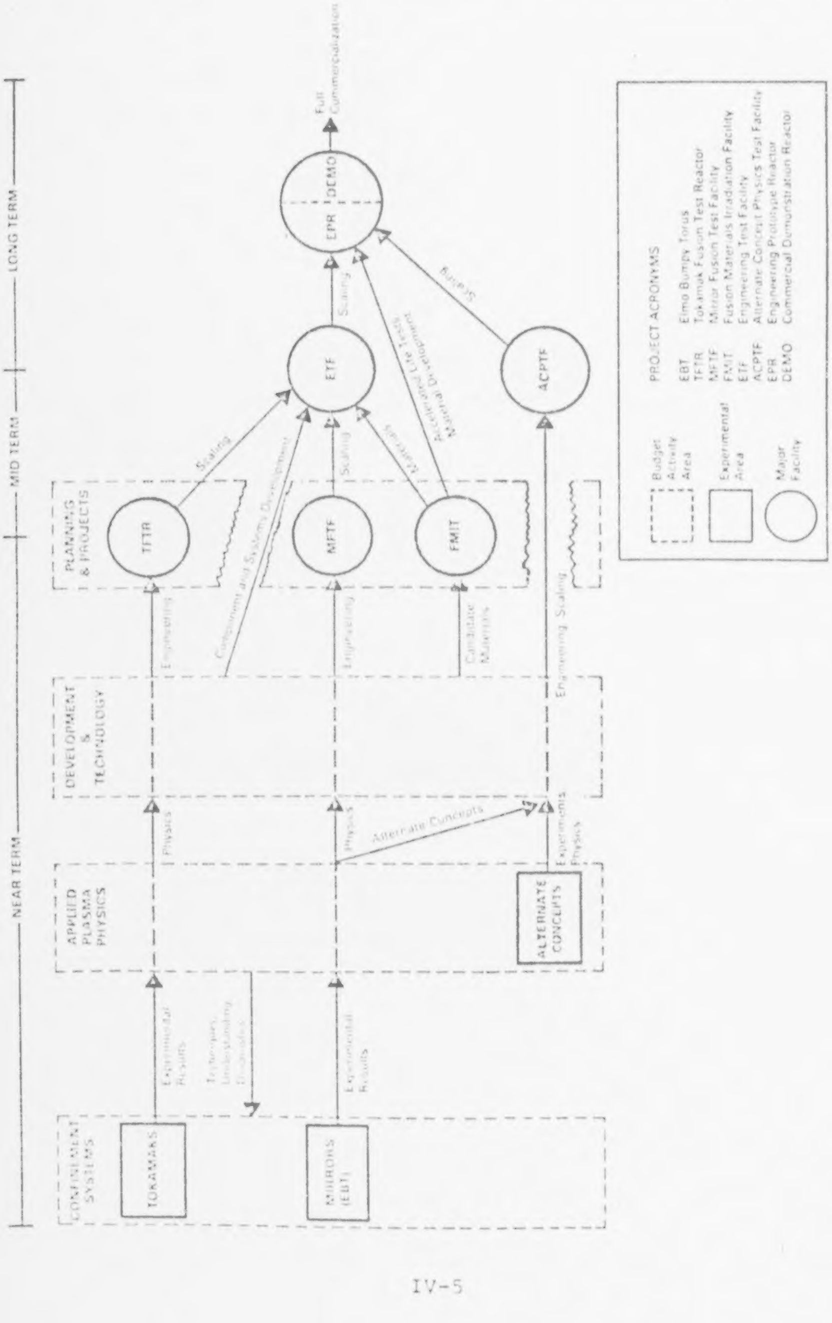
18. What is the present status of the internal support structure (ISS)?

19. Have the vacuum and controls systems been tested?

20. Has the cryogenic system been tested?

21. What is the milestone schedule for integration of subsystems and systems in TFTR?

(Guide for Additional
Question No. 13)



Program Flow

Department of Energy
Washington, D.C. 20585

MAR 2 1982

Dr. John V. Dugan, Jr.
Staff Director
Subcommittee on Energy Research
and Production
Committee on Science and Technology
U.S. House of Representatives
Washington, D.C. 20515

Dear Dr. Dugan:

The attached material is in response to the questions addressed in your letter of 29 December. I am pleased that you and other members of the HS&T staff took the time to be briefed on the Magnetic Fusion Program by several of the DOE Headquarters staff responsible for various elements of the fusion program. As you are aware, Mr. Kintner recently resigned. We are now in the process of identifying a new Associate Director for Fusion.

The changes in the national economic picture are likely to influence the future course of the fusion program. Until a permanent Associate Director has been named, and until some reviews of the fusion program activities have been done by the Department, the answers to your questions should not be regarded as Departmental policy. Also, the findings of the ERAB are advisory and are still under consideration with respect to their possible adoption as policy or implementation.

Sincerely,

Al Trivelpiece

Alvin W. Trivelpiece
Director, Office of
Energy Research

Attachment

MAGNETIC FUSION ENERGY PROGRAM

1. The November 1981 report of the Research and Development Panel of the Energy Research Advisory Board entitled Federal Energy R&D Priorities, transmitted to Deputy Secretary Davis on December 4, 1981, by ERAB Chairman Roddis, found that small reductions in magnetic fusion program funding can be made relative to the President's FY82 budget request. Please comment on this finding.

The ERAB report on Federal Energy R&D Priorities considered DOE energy research activities in two categories, Energy R&D Programs and Science and Technology Base Programs, and the criteria used to rank priorities in each category were different. The fusion program is unique in that it shares characteristics with programs in both categories. It is therefore difficult to precisely categorize the program and the ERAB conclusions must be interpreted with this in mind. Furthermore, the ERAB report does not necessarily reflect DOE policy or internal priorities. It reflects the collective opinion of the Board. The following discussion is a possible interpretation of the Board's conclusions.

The fusion program was evaluated in the ERAB report using the Energy R&D criteria under the Electric Supply R&D category because of its primary long term goal. In this category fusion ranked lower priority relative to programs focussed on shorter term goals because it will contribute to national energy supply after the year 2000. It was in this context that the funding evaluation of a "little less" for fusion was made. However, it is clear that the fusion program also supports many activities similar to those which the ERAB report ranked as high priority and deserving of more support in the Science and Technology Base category, such as materials sciences, university research, and most of the U.S. scientific activity in plasma physics.

The specific comments on the fusion program, as noted on page 21 of the report, were very favorable. "ERAB members agree on the long-term importance of this program and that the primary Federal role should be to continue to sponsor a joint program of the federal laboratories, industry and university scientific communities to determine if fusion can be practical. The potential payoff is very large, but is much too far in the future for significant private sector support. There was agreement that a stretch-out of the program is possible if budgetary pressures demanded it, but maintenance of a substantial level of Federal R&D funding is judged to be essential. It is also recommended that an enhanced effort to examine the use of fusion for the breeding of nuclear fuels deserves consideration."

2. *The aforementioned report also recommends "that an enhanced effort to examine the use of fusion for the breeding of nuclear fuels deserves consideration."*

(a) Do you agree with this recommendation?

(b) What are OFE's current activities in this area?

(c) What efforts are planned in this area and what is the projected funding?

(a) We agree that breeding of nuclear fuels is potentially a very important application of fusion, and that achieving the technical capability for this application will require a major engineering development effort. The major portion of this effort, especially the first several (about five) years, would be dominated by activities characteristic of fusion engineering development in general, with little specificity with regard to end use application. The key to an enhanced effort on fusion as a fissile fuel breeder is aggressive development of fusion engineering technology, especially in the area of the blanket and shield design, to make possible the evaluation of the feasibility of this, or any other, end use application. At present this development is limited by overall fiscal constraint. We are pursuing hybrid specific questions in a balanced fashion within our new Blanket and Shield program.

(b) OFE is currently carrying out detailed studies of fusion-fission hybrid concepts, with emphasis both on breeding blanket design and integration of the fission breeder into a complete nuclear fuel cycle. Lawrence Livermore National Laboratory is managing the overall effort, with major subcontracts to TRW, Westinghouse, and General Atomic, and smaller supporting efforts by Oak Ridge National Laboratory and Princeton Plasma Physics Laboratory. The emphasis of the current work is on fission suppressed blanket concepts, in which fast neutron fission of the fertile material and fissioning of the bred fuel is minimized to enhance fissile fuel output and to produce substantial reductions in environmental and safety concerns.

(c) Future work is expected to involve a continuation of the design study activity to fully evaluate the feasibility of the fission-suppressed concept and to identify the relative advantages and disadvantages of alternate fission fuel cycles. In addition, effort will be directed towards incorporating key hybrid blanket design issues into ongoing or newly established blanket development activities such as First Wall, Blanket and Shield Engineering Testing program, and Blanket Neutronics. At present, funding levels are projected to parallel the growth in the base technology program over the next few years; however, this subject area will likely be reviewed in greater detail in the future.

3. *On page 2 of the DOE report DOE/TIC-11600 entitled "The Fusion Engineering Device: Executive Summary, it is stated: "The selection of the tokamak for FED should not and does not predestine the course of commercial development. The problems to be solved for FED are in large part generic to other approaches, and other promising alternatives to the tokamak approach will be pursued to the extent needed to ascertain their relative merit." Delineate in detail the "problems to be solved for FED" that "are in large part generic to other approaches," as well as those that are not.*

Table 3-1 provides the information requested for the engineering technology area for the four leading alternatives to the tokamak, identifying both problems which are generic and those which are not.

Most of the problems which are inherent to the tokamak concept will be addressed by the FED, although in some cases not to the degree necessary to obtain the data needed to proceed with the Fusion Demonstration Plant. As a result, to provide this supplementary information for the tokamak and that needed by other concepts, an engineering development program has been developed to complement the FED. Volume I of the FED document (DOE/TIC-11600) describes the testing to be done in the FED, and Volume VI describes the complementary test program. Table 3-2 summarizes the highlights of these mutually supportive test programs, indicating where the bulk of the development work will be done for the three different technology areas. The complementary test program has been tailored to provide information which will not be available, or not available in sufficient detail from the FED, but which is needed to ascertain the merit of various alternate fusion confinement concepts. The Table also shows that a good deal of generic technology and engineering data is available from existing large fusion projects. The FED will serve a similar role in supplying the more detailed data needed for the demonstration of engineering feasibility.

For the plasma physics, the degree of similarity of the problems facing various confinement concepts is directly related to the degree of similarity of the geometries of magnetic fields of the various concepts. As the magnetic field geometries affecting any specific confinement physics problem become more different, the problems become more unique. This relationship is shown in general terms by Figure 3-1. In the Figure, those concepts which are the most similar geometrically, and thus have the most similar physics, are in the same vertical column. Concepts listed in adjacent columns also share numerous characteristics, but are not as similar as concepts which appear in the same column. See the answers to Questions #8 and #9 for more details concerning the physics problems.

Table 3-1

TOKAMAK TECHNOLOGY AREA	CONCEPT			
	TANDEM MIRROR	EBT	RFP	MODULAR STELLARATOR
First Wall	← Similar to Tokamak →			
Blanket & Shield			△	
Vacuum Systems				
Blanket Processing				
Power Conversion				
Instrumentation				
Fueling	△	△	■	△
Heat Transport	●	●	△	●
Power Supplies	●	●	△	●
Magnets	● ↑	● ↓	△ ↓	△
Supplemental Plasma Heating	*	**	○	△
Divertor	○	△	Unknown ACPTP Required	△
Control	Concept--Specific--ACPTP Required			

● Moderately Different from Tokamak, Not Pulsed

■ Moderately Different from Tokamak, Batch Versus Continuous Process

△ Highly Similar to Tokamak

○ Not Applicable

↑↓ Required Magnetic Field Greater than (↑) or Less than (↓) that for Tokamak

* Tandem Mirror Requires Steady-state Neutral Beams with Energy Requirement Similar to Tokamak

** EBT Requires Steady-state RF with Frequency Requirement Similar to Tokamak

ACPTP = Alternate Concept Physics Test Program

Table 3-2

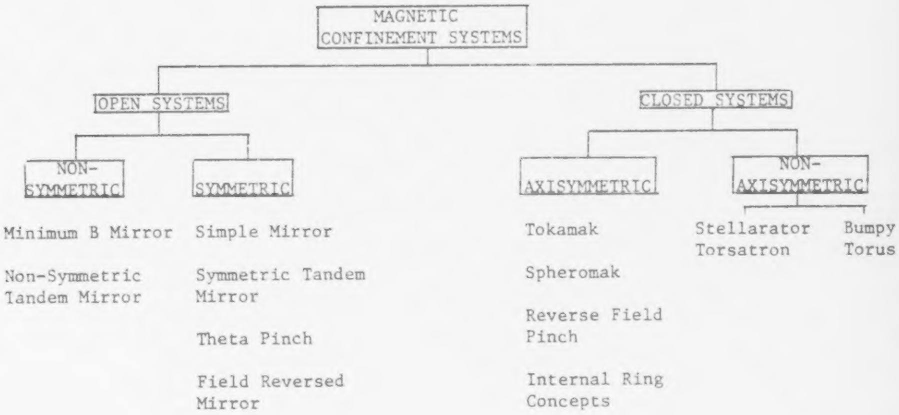
TECHNOLOGY DEMONSTRATIONS OF ENGINEERING FEASIBILITY

TECHNOLOGY	TFTR MFTF-B EBT-P	TSTA	FMIT RTNS-II	FED	COMPL. PROGRAM
PLASMA PRODUCTION					
MAGNETS	••	—	—	••	•••
CRYOGENIC SYSTEMS	••	•	—	•••	—
RF SYSTEMS	••	—	—	••	•••
PLASMA FUELING	••	—	—	•••	•
PLASMA DIRECT RECOVERY	•	—	—	—	•••
NEUTRAL BEAM SYS.					
POSITIVE IONS	••	—	—	•••	—
NEGATIVE IONS	—	—	—	—	•••
VACUUM SYSTEMS					
SURFACE TREATMENT	••	—	—	•••	•
CONTINUOUS PUMP	—	•	—	—	•••
POWER SUPPLIES/ENERGY STOR.	••	—	—	•••	•
NUCLEAR TECHNOLOGY					
FIRST WALL COMPONENTS					
NEUTRONIC PROPERT.	—	—	—	••	•••
THERMAL/HYDR.	•	—	—	••	•••
BLANKETS					
NEUTRONICS	—	—	•	••	•••
THERMAL HYDR.	—	—	—	••	•••
FUEL HANDLING					
PLASMA EXHAUST	•	•••	—	•••	—
BLANKET RECOVERY	—	—	—	••	•••
SHIELDING	•	—	•	•••	—
SYSTEM TECHNOLOGY					
INSTRUM/CONTROL	••	•	—	•••	—
SAFETY/ENVIR.	•	••	—	•••	—
MAINT./REMOTE	•	—	—	•••	—

•SUPPORTING INFORMATION
••SIGNIFICANT CONTRIBUTION
•••NECESSARY FOR ENGR. FEASIBILITY

Figure 3-1

TAXONOMY OF MAGNETIC FUSION CONFINEMENT CONCEPTS



4. Also on page 2, it is stated that the approach to the implementation of a formal U.S. policy on fusion research "was arrived at through the diverse talents and skills of laboratories, universities, and industries in a national effort to utilize the unique skills of each organization for the benefit of a national fusion program." What are the skills that are unique to each organization which have significant roles in the various subactivities?

Each organization and its unique skills are discussed separately below:

1. Laboratories - The bulk of all fusion research in the United States is being conducted in laboratories owned by the Government. The largest and most advanced fusion experimental devices to date were designed under the leadership of the laboratories, and these devices are located at and operated by the laboratories. As a result, the laboratories possess large staffs which are well versed in the state-of-the-art of fusion science, both the plasma physics aspects and the advanced engineering developments. In general, when various facets of fusion physics and technology require investigation and development, and expertise does not exist in industry, the laboratories will be called upon to do the required work because of their broadly qualified staffs, background experience in fusion research and access to the laboratory's test and development facilities.

2. Universities - In many respects, the skills of the universities are similar to those of the laboratories, but with a different emphasis. The universities also have skilled staffs with considerable experience in fusion research and they operate plasma test devices. However, their staffs are generally smaller than those of the laboratories and their experimental devices are certainly smaller and less capable than the devices operated by the laboratories. Despite this smaller scale of operation, the universities often attract researchers of an intellectual caliber at least as great as those at the fusion laboratories, due to their academic atmosphere and independence. These individuals serve three functions:

a) They provide a capability to conduct independent double checks of the work done or recommended by the laboratories.

b) They are a source of innovation, insulated from what might be an entrenched line of reasoning in the fusion laboratories. In this, their smaller and less expensive experimental devices provide a good mechanism for quickly and relatively inexpensively conducting the initial feasibility testing of new ideas.

c) They provide a more rapid access to new ideas developed in other fields than might otherwise be possible due to the closeness of the academic environment and its traditions of transferring information.

The universities are obviously also the initial training ground and source of manpower for the fusion program.

3. Industry - Industry is primarily relied upon as a source of engineering expertise, construction capability, commercial experience and project management capability for large projects. The limitation of industry is that, compared to the laboratories and universities, they have relatively little expertise in fusion and in some cases even in areas of engineering as specifically applied to fusion research. However, whereas the laboratories may know the latest developments and concepts, the industries know what can reliably be built, operated and maintained in less than ideal conditions.

The descriptions above are obviously generalizations. Although inspection of any specific fusion laboratory, university or industry may indicate considerable differences, the average of all their capabilities and limitations should fit these general descriptions.

Given this general background, Table 4-1 attempts to describe in a few words the most notable characteristics of the specific organizations which contributed to various aspects of the FED design work documented by DOE/TIC-11600 (for a complete list of contributors, see Volume II, page iv of DOE/TIC-11600).

Table 4-1

1. Design Overview
    a. Oak Ridge National Laboratory (ORNL) - Overall familiarity with the fusion program.
    b. Westinghouse - General familiarity with the fusion program and project management experience.
2. Plasma Design Analysis
    a. ORNL - Knowledge of fusion plasma physics theory and experiments with special capabilities in computer modeling.
    b. Princeton Plasma Physics Laboratory (PPPL) - Knowledge of fusion plasma physics theory and experiments with special experience in radio frequency and neutral beam plasma heating.
    c. University of Michigan - Radio frequency assisted plasma startup.
    d. General Electric (GE) - Transport theory and impurity control.
    e. General Atomic (GA) - Plasma disruption theory.
3. Systems Engineering
    a. ORNL - Experience in fusion plant trade-off studies.
    b. Burns and Roe - Conventional construction and support system design.
    c. Grumman Aerospace - Complex structural design and design integration.
    d. Bechtel - Conventional construction and support system design.
4. Magnetic Systems
    a. Massachusetts Institute of Technology (MIT) - High field, superconducting magnet design.
    b. GE - Stress analysis, superconducting coil design.
    c. Argonne National Laboratory (ANL) - Superconducting coil design, eddy current effects.

   d. PPPL - Magnetic field calculations.

   e. ORNL - Magnetic field/plasma equilibrium interactions.

5. Nuclear Systems

   a. GA - Mechanical engineering and nuclear engineering.

   b. PPPL - Tokamak electrical systems design.

   c. ANL - Impurity control.

   d. McDonnell Douglas - Mechanical and thermomechanical design.

   e. Bechtel - Conventional construction.

   f. Los Alamos National Laboratory (LANL) - Electromagnetic design.

6. Plasma Heating Systems

   a. PPPL - Plasma heating system design.

   b. Lawrence Berkeley Laboratory - Neutral beam system design.

   c. GE - Electrical system design.

   d. ORNL - Neutral beam system design.

7. Reactor Support Systems

   a. PPPL - Machine design/plasma physics interactions.

   b. ORNL - Fueling.

   c. GE - Electrical power system and control system design.

   d. GA - Nuclear engineering.

   e. Mound - Tritium systems design.

   f. MIT - Mechanical design.

8. Facilities

   a. Burns and Roe - Conventional construction and support system design.

   b. Bechtel - Conventional construction and support system design.

5. What are the detailed FY80, FY81, FY82, and FY83 funding levels and program milestones for the following subactivities of the Applied Plasma Physics activity: 1) Experimental Plasma Research, 2) Advanced Fusion Concepts, 3) Computer Services and Technology, and 4) Fusion Plasma Theory? Please provide justification of how each of the major tasks/projects carried out in these subactivities support the stated subactivity objectives. How are these elements being realigned to support a focused physics program?

The funding levels and program milestones for each activity within Applied Plasma Physics are described below.

I. Experimental Plasma Research

A. Funding Levels - BA, Op (000's)

	1979	1980	1981	1982
EPR	12,310	11,742	18,389	15,500

B. Justification of Activity Relative to Objectives

The Experimental Plasma Research program supports studies with the objective of developing new techniques and providing extensive data for the design, operation and understanding of large confinement experiments and commercial-scale reactors. Projects are tied to critical issues and needs of the fusion program and are primarily carried out by means of small, special-purpose experiments. The program is divided into five major technical areas.

1. Plasma Heating and Current Drive

Experiments on Versator at Lower Hybrid (LH) and Electron Cyclotron Resonance Heating (ECRH) frequencies, on PRETEXT and Tokapole at Alfven frequencies, on Macrotor at Ion Cyclotron Resonance Heating (ICRH), are directed at physics understanding of the coupling of energy at these frequencies into tokamaks, on the propagation of this energy, and on how it is deposited in the plasma.

2. Plasma Properties

The LAMEX facility (UCLA), the mirror device (UC/Irvine) and Constance (MIT), are to demonstrate and understand stabilization in mirror machines using simple techniques. The Irvine machine is working on stabilization of the flute instability so that complicated minimum-B mirror end plugs might not be needed in tandem mirror systems. The Constance experiment is demonstrating stabilization of drift cyclotron loss cone modes in minimum-B systems and is also determining the behavior of "sloshing-ion" distributions in mirrors, distributions that are expected in TMX-U. LAMEX is to verify stabilization with very high mirror ratios. Tokamak experiments include Tokapole (Wisconsin), Microtor (UCLA), Torus II (Columbia), and TERP (Maryland). Tokapole is to obtain data on neutral wall reflux and on the effects of divertor plates on stability, and also to correlate the onset of MHD instabilities with current density and q-radial profiles. Torus II and TERP are determining the parameters of very high beta operating regimes in tokamak-like plasmas. Microtor is demonstrating the effectiveness of pumped limiters for impurity control and the effect on impurities of the discharge walls operating at elevated temperatures, as they will in any reactor.

3. Atomic Properties

Radiative rates and cross sections for excitation, ionization and charge exchange are measured for multiply charged impurity ions (O, C, N, Fe, Ti, Cr, Ni) in experiments at ORNL, NBS, PNL and Maryland. These measurement programs are closely coupled with theoretical projects supported by the theory branch so that particle losses and radiative power emitted from fusion devices can be calculated and spectroscopic measurements of impurity line strengths can be converted to impurity concentrations. A second area of atomic physics research (LBL, Wesleyan, SRI) is the determination of atomic and molecular processes that contribute to negative hydrogen (H^-) concentrations in ion sources. The objective is to develop improved negative ion sources for the next generation of high energy neutral beam injection systems.

4. Plasma Diagnostics

Three projects are developing techniques to measure B-field and plasma current density. This cannot yet be measured well in fusion devices and is probably the most important factor in disruptive low-q operation and associated impurity influx. In addition, a local measurement of current density is necessary to analyze experiments aimed at determining beta limits. ORNL is testing a scheme based on Faraday rotation of a Far infrared (IR) laser beam, while GA and TRW are working on two different versions of a Zeeman splitting technique. RPI is developing improved ion-beam systems to measure electric potential and is attempting to obtain measurements of density and potential fluctuations as well. Far IR systems have been developed in past years and are now being demonstrated to measure ion temperatures, B-field and fluctuations. Ultraviolet and soft x-ray spectroscopy is applied to TMX, EBT, ISX and the two Alcator devices by Johns Hopkins University, NRL, AS&E and the Smithsonian Observatory.

5. TEXT

TEXT is a national user facility that is utilized for a wide variety of support experiments. This facility provides university, industry and DOE laboratory scientists access to a medium-scale tokamak with kilovolt plasmas. TEXT experiments include work on limiter erosion and pumped limiters, disruption effects, plasma diagnostics and atomic and molecular behavior. These experiments are scneduled around a "core program" addressing anomolous electron transport, which is conducted by on-site experimentalists on the University of Texas staff, with diagnostic support from RPI, UCLA and other off-site users.

C. Milestones

The status of each program milestone is summarized. Some milestones are the result of activities of several contractors who together provide the data or demonstration needed to achieve the milestone.

1. TEXT

- Complete TEXT Fabrication - September 1980
- Begin User Experiments - March 1981

These milestones have been accomplished. TEXT was completed essentially on schedule. First plasma was obtained in November 1980. The first user experiments were conducted by NRL and NBS and spectra of impurities have been obtained. New forbidden lines of iron have been identified for use in ion temperature tokamak diagnostics.

2. Plasma Properties

- Explore High Beta Stabilization - October 1981

The Torus II experiment at Columbia University has provided preliminary indication of the second region of tokamak stability of high beta (over 13%). The data is clouded by the effects of impurities and the short discharge time available in this machine. The project is continuing to provide improved data. A major review of the project is scheduled for January 21, 1982.

- Evaluate Flute Stabilization - May 1982

Initial experiments in 1979 at University of California, Irvine, showed stabilization of the flute instability in a simple plasma. Fabrication of a small mirror facility is continuing at Irvine to test stabilization in an actual mirror device. The project has been slowed by reduced APP funds so that this milestone will be delayed by one year. A simple means of stabilizing this instability would be of major benefit to tandem mirrors by allowing the use of simple, symmetric mirror coils which are not only less expensive but are also expected to lead to less radial particle transport than nonaxisymmetric coils.

3. Radio Frequency (RF) Heating and Current Drive

   o Begin Alfven Heating - October 1980

   Experiments were begun on PRETEXT at the University of Texas to demonstrate antenna designs and coupling to the plasmas. This is the only U.S. program directed at the utilization of Alven waves.

   o Achieve Lower Hybrid (LH) Current Drive - March 1981

   This was accomplished on ACT at PPPL in September 1980 and at higher currents in an actual tokamak on Versator at MIT in November 1980. The project at Versator is directed now to obtain much improved coupling to the plasma. The developments in this project on Versator have provided the data and successes needed to proceed with much larger LH experiments on Alcator C and PLT.

   o Complete ECRH on Versator - October 1981

   This NRL project at MIT will be completed in March 1982 and then sent to ISX at ORNL for use in new experiments on ECRH current drive. The project has been slowed by budget restrictions and inadequate staff at MIT. Data on coupling of ECRH to tokamak plasmas has been achieved.

   o Evaluate RF Heating - December 1982

   This milestone is to review and evaluate the APP RF heating program for its effectiveness and accomplishments so far, and to plan any further activities through FY83 and FY84. The APP program has provided critical first steps in Alfven heating (PRETEXT, 1981), current drive (ACT and Versator, 1980), and ECRH (ISX, 1979, and Wisconsin, 1978).

4. Diagnostics

   o Demonstrate Far IR for Ion Temperature - October 1980

   The far IR program has developed lasers, detectors, receivers, beam dumps and scattering systems starting from scratch in FY76. As the program proceeded, several diagnostic techniques were developed in addition to ion temperature. The first measurements of ion temperature were obtained in laboratory plasmas at UCLA in January 1980 using low power, continuous wave (CW) scattering systems. The system has been improved to measure ion temperatures and density fluctuations in Microtor at UCLA in 1981. Faraday rotation measurements of magnetic fields and density interferometers have been demonstrated with Far IR at MIT (1978, 1981) and at ORNL (1979, 1981). High power, pulsed Far IR systems to measure ion temperatures by Thomson scattering will be demonstrated in Alcator C in 1982.

- Demonstrate Fluorescence Measurements of Neutral Hydrogen Density - October 1981

The University of Maryland has developed laser systems that generate the required Lyman-alpha ultraviolet radiation needed for this scattering technique. The program has been slowed by personnel changes at the University. First measurements are expected on EBT-S at ORNL by December 1982.

- Demonstrate Current Density Diagnostics - October 1982

Current density (current as a function of position) is directly related to the poloidal magnetic field and several techniques are under development to measure magnetic field. Faraday rotation of beams passing through the plasma at far infrared wavelengths has been demonstrated in a simple one-channel system. A five-channel ORNL system to obtain profiles in ISX will provide results by October 1982. Two alternate Zeeman splitting techniques (at GA and TRW) will be demonstrated on fusion machines in 1983 and 1984. These are more complicated but provide local (not line-integrated) results. APP has increased its funding for projects on this subject as the internal, local magnetic field remains the most important parameter not yet measured in fusion devices.

5. Atomic Data

- Molybdenum Radiation Model - October 1980

- Iron Group Data - October 1981

The model of radiation from molybdenum impurities was completed by LANL in October 1980 using atomic data from several other contractors. Data for iron, chromium, nickel and titanium is not yet complete. The rate of progress has been slowed by budget reductions but an additional reason for not finishing this past year is that much more data for these elements is required than was originally identified when the milestone was set three years ago. Lines of these elements are now used for temperature and impurity diagnostics and the need for the identification of many lines has become critical. Data on iron itself is fairly complete. Emphasis is now on titanium.

- Surface Data - February 1983

The measurement or calculation of surface data has been abandoned because of budget limitations. The atomic data center at ORNL will continue to compile and make surface data available to the plasma community as it is generated by other (non-APP) programs.

6. Superconductor Materials Research

- Demonstrate Scale-Up of Improved Superconductor Material Process - January 1981

- Fabricate Long Superconductor Wires by Improved Processes - October 1981

This subactivity is aimed at developing and testing new, improved processes and materials specifically to meet fusion needs. It is distinctly separate, longer range and much smaller than the superconducting magnet development effort in the Development and Technology program. Scale-up of new processes developed in APP has not been possible since the funds have not been available to involve superconductor manufacturers to the extent previously planned. However, fabrication of long wire was accomplished by October 1981 by utilizing MIT laboratories along with the partially scaled-up technology.

- Transfer New Technology to Industry - October 1982

This task will be accomplished gradually over approximately three years as funds permit. The rate of progress is also dependent on the extent to which manufacturers can involve themselves in this project. Their funds are also severely restricted.

- Evaluate New Materials - October 1983

This task has been postponed indefinitely as it is uncertain that the cost of an industrial capability for a new material can be justified. Emphasis will remain on new processes for the present Nb_3Sn material. A decision to proceed again to investigate new materials will be regularly considered.

II. Advanced Fusion Concepts

A. Funding Levels - BA, Op (000's)

	1979	1980	1981	1982
AFC	14,398	12,336	16,495	17,300

B. Justification of Activity Relative to Objectives

Based on recent technical achievements, there is a high degree of confidence that a burning fusion plasma will be demonstrated in a tokamak in the near future and that tokamaks can be developed into reactors. In addition to the mainline programs, development of alternate fusion concepts is supported by the Office of Fusion Energy for their potential to provide optimized reactor designs which may offer advantages over the standard configurations with respect to:

- Capital Costs
- Maintainability
- Material Lifetimes
- Design Simplicity
- Safety
- Tritium Inventory

Consistent with the Department's policy of developing the maximum potential of fusion for commercial application, a balanced program of investigating and assessing alternate approaches with various reactor options is being pursued. The alternate concepts include a variety of physics options in addition to the mainline reactors discussed above. By supporting these alternates, the matrix of confinement physics possibilities is being completed. Thus, a balanced development of confinement physics as well as reactor options is included within the OFE development program.

The present Advanced Fusion Concepts program includes major subprograms in the reversed field pinch and compact toroids at a number of laboratories. A smaller component of activity seeks to develop the possibilities of alternate fusion fuel cycles. At present, multipole development is supported in the AFC program as a potential confinement configuration for the high temperature fusion fuel cycles (those based on proton reactions). Optimized versions of mainline approaches (advanced tokamaks and tandem mirrors) are considered candidates for confinement of the lower temperature fusion fuel cycles (those based on deuterium reactions). Finally, a seminal level of activity has been maintained for several years to evaluate the prospects of torsatron configurations and to allow a meaningful U.S. collaboration with Western Europe, Japan and the Soviet Union in this area.

The reversed-field-pinch (RFP), like the tokamak, is a toroidal, axisymmetric confinement device. Both systems use a combination of poloidal and toroidal magnetic fields to confine a plasma in a minimum energy state. For both systems the poloidal field is created by inducing a large toroidal plasma current. Attractive RFP features include:

- Device size can be chosen solely on the basis of engineering consideration and not by physics constraints.
- The beta limits predicted for the RFP are considerably greater than that for tokamak systems.
- The plasma may be brought to ignition by ohmic heating alone.
- The confinement of plasma with high-to-moderate beta is achieved primarily by poloidal fields, which characteristically decrease with increased distance from the plasma, thereby considerably reducing fields and stresses at the coils.

These advantages are unique to a system that derives its confinement primarily from self-generated fields.

Compact toroidal systems (CT) are characterized by the lack of any magnetic field generating conductor that links the plasma configuration externally. It is anticipated that this substantial modification will permit maximum simplicity in the designs of blankets and shields (solenoidal or spherical). CT's are closed magnetic systems which may or may not have a toroidal field. Reactor advantages include flexible output power and significant technological simplifications. At present there are several reactor embodiments which have been studied in varying degrees of sophistication ranging from low to moderate. They utilized single or multiple cells, stationary or moving. Recent experimental advances in this area have been significant.

Alternate fuel cycle systems offer the greatest possibilities of minimizing the environmental impact of fusion power systems. It may be possible to reduce or eliminate tritium inventories, improve plant efficiencies to about 60% by use of direct conversion, decrease induced radioactivity, and increase first wall lifetimes. These fuel cycles require higher ion temperatures and beta values than D-T cycles. For this reason, the present mainline low beta toroidal systems will probably not be acceptable confinement systems, and others must be developed. One class of candidates consists of multipoles of various orders.

The torsatrons are toroidal devices in which the magnetic coils are wound at an angle around the toroidal plasma vessel. The advantage of this arrangement is that a toroidal plasma current is not required and hence the devices can operate in steady state. One problem with the arrangement is the fabrication and support of the magnet windings. Current efforts are oriented toward design studies, theoretical work and limited experimental studies.

The program is managed in a dynamic way. The alternate concepts, generally speaking, are at a relatively early stage of development with attendant higher risk. Testing of the most promising advanced concepts helps to ensure that the best reactor approaches will be available for development into commercial reactors. As definitive research results become available for a concept at any developmental level, decisions will be made either to advance that concept or to terminate support. Funding priorities among the concepts are based on reactor attractiveness and technical and programmatic considerations. Periodic evaluations of concepts at all levels are conducted to ensure up-to-date information on which to base funding decisions.

C. Milestones

Program accomplishments (and milestones) in this subactivity are strongly influenced by the availability of funding. Program objectives have had to be rescheduled in recent years to accommodate reduced activity required by available funding. The present objectives and schedules are described by topical area below.

1. Reversed Field Pinch

The near term objectives in the RFP development have been drastically overhauled as a result of the recent rapid progress from the ZT-40 device at LANL. Original objectives have been met or exceeded by these results; new objectives have been identified. Specifically, the experimental duration and heating are at 10 milliseconds and 350 electron-volts respectively, both exceeding the administrative goals of the ZT-40 project. These accomplishments led to new near-term objectives:

- Extended Rise Time Start-Up

Slow rise time startup operation has strong economic significance for reactor performance. Begin modification to slow mode operation (0.1 millisecond).
ACCOMPLISHED October 1981

Conduct operations at 0.25-1.0 milliseconds rise time. Evaluate experimental results.
October 1982

- Limiter Studies

Mechanical limiters to shield walls from unpredicted current termination are essential to allow operation at full performance 600 kA. Complete design and evaluate test results.
July 1982

- Maintain Extended Duration Equilibria

At present 10 millisecond experimental operation far exceeds the design value of 2 milliseconds because of outstanding success in operations. Complete modifications to maintain 30 millisecond equilibria, and conduct initial tests.
November 1982

- Gas Puffing

Extended duration operation requires density replacement. Complete initial gas puffing tests.
April 1982

- Energy Transport

Present operations at 5 kG field strengths are to be extended to 15 kG by operations at 600 kA (see above), and will permit study of energy transport scaling with field and temperature. Begin evaluation of preliminary tests.
July 1982

2. Compact Toroid Development

Rapid and outstanding progress during the last two years has led to accomplishments and analyses of formation, equilibria, and magnetohydrodynamic (MHD) stability of two alternate compact toroid configurations, i.e., field reversed configurations (FRC) and spheromaks. Each has distinct advantages and has proven successful. It is not now possible to decide which is better with present results. This step, selection of one CT configuration, the principal program goal, has had to be postponed to the 1984-1985 interval because of reduced funding. Development steps include the following objectives (past and present):

- Evaluate spheromak equilibria and stability from Maryland experiments. Successful results confirmed program direction and organization.
  ACCOMPLISHED October 1981

- Evaluate results of spheromak impurities control studies. Impurities are presently limiting experimental lifetime.
  August 1982

- Initiate reduced performance S-1 spheromak operations. A staged completion has been adopted to allow for the earliest possible experimental results.
  March 1983

- Complete fabrication of S-1 spheromak.
  RESCHEDULED DUE TO REDUCED FUNDING October 1983

- Initiate full performance S-1 spheromak operations.
  October 1983

- Complete fabrication of CTX Facility (LANL).
  ACCOMPLISHED January 1980

- Evaluate Toroidal Spheromak Source (LANL) and install on CTX facility. This demonstrated successfully an economical spheromak source.
  ACCOMPLISHED February 1980

- Initiate operations on CTX facility. This is the chief experimental device in the LANL CT program. Both types of CT configurations are to be studied in it - a unique capability.
  ACCOMPLISHED April 1980

- Complete fabrication of FRX-C Device.
  ACCOMPLISHED July 1981

- Evaluate initial performance of FRX-C Device. Modest engineering modifications are being completed.
  ACCOMPLISHED October 1981

- Complete initial performance optimization of FRC Device (FRX-C).
  July 1982

- Begin FRX-C experiments on CTX Facility. More complete diagnostics exist on CTX facility for energy confinement studies.
  POSTPONED BECAUSE OF REDUCED FUNDING October 1981

- Evaluate FRC Energy Confinement Studies. A crucial step in selection of optimum CT configurations.
  December 1983

- Initiate FRC Translation Studies. Many CT reactor scenarios involve movement of the plasma configurations.
  July 1982

- Complete preliminary auxiliary heating studies for spheromaks. CT's require auxiliary heating to heat ions and extend lifetime.
  March 1983

- Evaluate energy transport in collisionless spheromak plasma. A crucial step in selection of optimum CT configuration.
  July 1984

3. Alternate Fusion Fuel Studies

- Complete Surmac upgrade and begin neutral beam heating. This provides auxiliary heating for this configuration.
  ACCOMPLISHED April 1980
- Evaluate Surmac neutral beam heating. Auxiliary heating works well, however, electron temperature remains much lower than 1 keV ion temperature.
  ACCOMPLISHED April 1981
- Begin RF Heating on Levitated Octupole. This effort tests methods of auxiliary electron heating for octupoles.
  ACCOMPLISHED January 1980
- Begin neutral beam heating on Levitated Octupole. Auxiliary ion heating required for this configuration.
  ACCOMPLISHED June 1980
- Evaluate status of Octupole confinement experimental results including auxiliary heating of ions and electrons.
  June 1982
- Complete assessment of potential of alternate fusion fuels to fusion development.
  December 1983

4. External, Non-Axisymmetrical Confinement (Torsatrons, Stellarators, etc.)

- Evaluate studies of Modular Coil Designs that are deemed necessary for reactor performance. Several modular designs were produced and were reasonable from physics and engineering standpoints.
  ACCOMPLISHED October 1980
- Evaluate World-Wide Torsatron Experiments and publish report. This review and assessment was conducted by a Joint U.S.-Euratom Committee that found outstanding experimental progress and recommended future directions.
  ACCOMPLISHED July 1981
- Complete workshops to define future directions and development goals. This process will convert the U.S.-Euratom Report into detailed plans.
  January 1983

- Commence experimental operations with modular stellarator. This is a modest study of the implications of coil modularity to confinement physics.
  March 1982

- Evaluate new helical configurations. Several radical configurations have been conceived and are under development. They will be evaluated for program significance.
  October 1982

D. Focussed Physics Program

The Advanced Fusion Concepts subactivity supports experimental tests of fusion concepts which are alternatives to tokamaks and mirrors. An important factor that is becoming increasingly apparent in the fusion power development program is the convergence of various fusion approaches. This can be read as a maturing of the science as the various confinement configurations are unified by common underlying physical principles. This has two substantial consequences to the development program:

1. Engineering and technology development programs directly relevant to the mainline confinement approaches are also relevant to many of the alternate concepts.
2. Experiment and theoretical advances in the mainline areas of heating, confinement physics, computational techniques are immediately transferable to alternate concept research programs. This is particularly true in the toroidal confinement concepts in which reversed field pinch, compact toroid configurations and torsatrons have many similarities to the tokamak configuration (and vice versa).

The benefits of this convergence are that the cost of alternate concept development is reduced and the programs should be able to proceed at a faster development pace because of the successful experiences in the mainline efforts. As a corollary, funding of alternate concepts does not diffuse program emphasis. These activities are in a real sense intended to produce significant reactor advantages and improve the ultimate reactor configuration based on the convergence of the confinement approaches.

III. National MFE Computer Network

A. Funding levels - BA, Op (000's)

1979	1980	1981	1982
11,469	11,716	11,445	13,200

B. Justification of Activity Relative to Objective

The Magnetic Fusion Energy Computer Network provides integrated computing resources to all parts of the magnetic fusion program. Several types of computers are maintained, so that different levels of computing, from experimental data processing to large scale scientific calculations, can be accommodated in a cost-effective manner. The central node of the network is the National Magnetic Fusion Energy Computer Center (NMFECC), at Livermore, California. Large scale computing is provided by a CRAY-1S, a CRAY-1, and a CDC 7600 computer, backed by a disk farm, a mass storage device, and an automated tape library. Satellite links connect the NMFECC with User Service Centers at PPPL, ORNL, LANL, GA, and LLNL. Each of these has a DEC System-10 for medium scale computing and for high speed access to the other nodes. Smaller computers are attached to form internal computer networks. Fifteen other nodes are connected by low speed dedicated phone links, and another 30 institutions are served by dial-up lines, ARPANET, and TYMENET. The network provides essential computing to all contractors regardless of location. It allows low cost resource sharing of codes and computers. With proper authorization, users at any node can access other nodes for experimental data analysis. The resources of the Computer Network serve experimentalists, theorists, engineers, and technologists.

C. Milestones

- Replace Class IV Computer by Class VI Computer - FY81

This milestone was achieved in September 1981 when the CRAY-1S computer was installed at the NMFECC. Within a few days of installation the computer was accessible through the network, and by October 1981 was fully utilized with less than 1% idle time. At the same time the CDC-7600 computer took over file handling and accounting functions previously handled by the CDC-6400. The latter computer is being temporarily retained as a back-up for file handling, but it will be decommissioned due to lack of funding.

Approximately half of the CRAY-1S is used for engineering calculations and experimental data analysis. A significant new application for this computer is stress analysis, which aids in design and testing of mechanical components such as magnetic coils and vacuum vessels.

- National MFE Computer Center's New Facility - FY81

In September 1980 the NMFECC moved to its new facility at Lawrence Livermore National Laboratory. The new $5 million facility consists of a building with approximately 40,000 square feet, gross floor area. Prior to moving into the new facility the NMFECC staff and equipment were housed in four separate quarters ranging from a converted World War II army barracks to temporary trailers. The highlight of the move was centered around the rapid deinstallation and installation of the two super class computers, a CDC-7600 and the CRAY-1. Both machines were shut down and brought back into full operation in less than five days. Machines of this size have never been moved with such success in such a short time span.

- Satellite Links for the MFE Computer Network - FY82

In May 1981 the first computer satellite in DOE was installed to connect the Princeton Plasma Physics Laboratory to the NMFECC at Livermore. The satellite system replaced the AT&T wide band service (50 kilo bits per second) which was more costly and less reliable than satellites. After a six month evaluation period, Oak Ridge, Los Alamos, and General Atomic were also switched over to the satellite system. The latter two installations were completed in early January 1982. In addition to the higher reliability and better quality service, the satellites have proven to be very cost effective. The four AT&T links were costing $43,000 per month and increased to $99,600 per month in August 1981. Had we not converted to satellites this year, our communication costs would have increased by $668,000 per year and within three years would increase by $870,000 per year, provided no additional rate increases were approved for AT&T.

- Computer Upgrades for the User Service Centers - FY82

In mid-January 1982, the Office of ADP Management signed off on the implementation plan for the MFE mid-scale computers. This was a single procurement handled by the staff at the National MFE Computer Center at Livermore and was made sole source to Digital Equipment Corporation. The packaged arrangement allowed for a significant cost savings of a minimum of $250,000 to slightly over $500,000, depending upon allowances for trade-in equipment. This procurement brings all the User Service Centers (USC's) up to the same level of equipment configuration and will upgrade the level of in-house computer support needed at those sites plus the ability to maintain the computer resource sharing throughout the community of MFE contractors.

IV. Fusion Plasma Theory

Major Theory Tasks:

A. Funding Levels

	1979	1980	1981	1982
Total	16,511	15,341	19,471	21,400

B. Justification of Activity Relative to Objectives

The purpose of fusion theory is to develop and apply models and mathematical techniques to describe the behavior of magnetically confined plasmas under actual operating conditions. Plasma models are developed and used to interpret results obtained in existing confinement devices. These models are subsequently used to develop new concepts and to predict performance parameters of future experiments and reactors. The theory activity is divided into four categories: tokamak theory, mirror theory, alternate concepts theory, and generic theory.

The first three of these provide analytical and modeling support for the specific confinement geometries. In these categories the effort is directed to central confinement and heating problems. The generic theory category provides broad-based support for the entire fusion program. Efforts in this last category include developing computer algorithms of general applicability, providing fundamental physics analyses and supplying required atomic data.

1. Tokamak Theory

Work has continued on high-beta tokamak stability under varying conditions of pressure gradient and shear. Particular attention has been focussed in the past year on the explanation of the "soft beta limit" under neutral beam injection in ISX-B. The device was modeled at varying magnetic fields and currents with the same beta to see whether the "limit" was due to instability. Preliminary conclusion is that the "limit" is due to deterioration of confinement due to inadequate toroidal current. RF current drive theory has now been supported by experiments, and work is proceeding to include effects of trapped particles and to model the density cut-off of the RF-driven current. New work has been initiated on the effect of poloidal and bundle divertors on energetic particles in the plasma, and new concepts of divertorless impurity control are being investigated. The task force in plasma wall plasma divertor interactions has been formed from various national laboratory and university components. The task force is doing urgently needed research in support of present diverted and divertorless tokamak experiments. Its output is expected to have a vital impact on FED design. Work is continuing on resistive MHD to study tearing modes, magnetic islands and stochasticity.

2. Mirror Theory

MHD ballooning mode studies in mirrors resulted in design change for the location of thermal barriers. Studies of resonant transport have led to preliminary identification of operating regimes and machine design in which enhanced losses can be inhibited. Studies were made of stability and power loss in a tandem mirror in which minimum-B stability for the end plugs is provided by high-temperature electron annuli. Studies indicate that considerable simplification over MFTF-B design might be effected by this approach. This could make feasible either a relatively compact, high power density D-T reactor, or a low power density D-D reactor.

3. Alternate Concept Theory

Alternate concept theory was focussed on the Elmo Bumpy Torus (EBT), reversed field pinch (RFP), and spheromaks. Scaling laws for EBT have been developed on the basis of experimental data and neoclassical theory. The presence of the "tilting mode" and the "shifting mode" was predicted in spheromaks, and techniques were developed to suppress these modes. A theoretical description of the startup of the RFP that agrees closely with experiment has been developed. Work has been initiated in advanced fuels to examine the feasibility of building machines that use cheaper fuels and produce either lower levels of activation or none at all.

4. Generic Theory

Continuing efforts in atomic physics have refined data for atomic processes in plasmas. Increased emphasis has been placed on collisional excitation to support studies of plasma-wall regions, and calculation of ionization states of heavy elements have contributed to the development of space-resolved ion temperature measurements. Studies of alkali metals have led to improved negative ion sources for high energy neutral beams. An Institute of Fusion Studies was organized at the University of Texas to study long-range generic theory problems, such as turbulence, which are fundamental to plasma confinement and also to examine a broad range of applied problems. The Institute will also serve as a center for U.S.-Japan theory exchanges.

Efforts in all four areas will continue in FY82 and FY83. The current program direction will be maintained, with continued progress in understanding the underlying physics of the various concepts expected. The role of fusion theory remains one of increasing the reliability of experiments and providing new ideas for improving plasma confinement. The high cost of confinement experiments places increased reliance on simulation to improve our understanding of fusion physics and engineering.

C. Theory Milestones

Below is a detailed description of milestones for fusion plasma theory. Milestones which are due in future fiscal years contain a rather detailed and up-to-date status report and a discussion of future work to be done. It should be borne in mind, however, that milestones for theory are written to cover broad ranges of efforts and do not always contain specific items to be accomplished by specific dates. The reasons for this are obvious. The theory effort must be kept flexible enough to respond to unexpected demands by the confinement program. A perfect example of this is the soft poloidal beta limit in ISX-B that has been the subject of a concerted effort on the part of the theoretical community. Another reason is that the physical models that are used to explain and predict experimental data must rely on timely experimental input, which is not under the control of the theory program. Thirdly, the theorists must have the freedom to pursue and apply new developments in fusion theory and in supporting sciences such as hydrodynamics, turbulence theory, numerical analysis and the theory of partial differential equations.

1. Tokamak Theory

o Alpha Particle Diffusion and Heating in Ripple Fields - FY82

The milestone is largely completed. The narrative is combined under Alpha Particle Diffusion and Heating.

o Alpha Particle Diffusion and Heating - FY81

Because tokamaks with burning plasma will have the blanket between the plasma and the coils, the diameter of the coils will be such as to produce low magnetic field ripple values in the regions of plasma where most alpha particles will be produced. The proposed burn control by means of ripple fields at variable intensity may be more difficult to achieve than previously thought. On the other hand, the expected ripple values present no problems for alpha particle confinement.

New results have been obtained concerning a number of effects in burning D-T plasmas in tokamak geometry. Careful re-analysis of fusion reaction rates in injected plasmas yielded an important increase in the fusion reaction rate by almost a factor of two. The fusion-born fast particle distribution may be subject to transient velocity-space instabilities which can lead to desirable anomalous ion heating. These modes are quenched by a rapid filling in of velocity space due to very good alpha orbit confinement. In tokamaks with advanced fuel cycles, instability heating can be a strong effect.

The strong alpha particle localization in the center of the plasma acts as a source of free energy which destabilizes the fundamental Alfven eigenmodes for alpha particle velocities greater than Alfven velocities. Recent estimates of the ensuing anomalous radial diffusion of alpha particles are large enough to provide ash removal, but not so large as to diminish alpha particle energy equilibration. This diffusion broadens the alpha deposition profile. The alpha population interacts with the pressure-driven ballooning modes of the plasma. The large Larmor radius of the particle has recently been shown to partially stabilize the modes which are deleterious to the confinement of the bulk plasma. The inherent asymmetry of the large alpha banana orbits leads to a net electric current in the same direction as the transformer-induced current in the tokamak. This effect acts as a natural current drive but is not large enough in itself to maintain a steady state.

All of these theoretical results are expected to be verified in a weak form in the first generation of burning tokamak experiments (TFTR, JET and the Japanese R project). A definitive test of these results will come in devices with $Q > 5$ where alpha particle power exceeds the thermal power of the background plasma.

- Ballooning and Resistive Instabilities - FY83

Extensive efforts in analytic and computational MHD have permitted calculation of beta limits as a function of elongation and density and current profile of the plasma. Resistive calculations have produced estimates of magnetic island widths in the plasma and codes have been developed to model disruption in tokamaks. The work is continuing.

- Feedback Stabilization of Tearing Modes - FY86

Equilibrium and stability codes developed in all major laboratories are now capable of modeling the effect of individual coils on the plasma equilibrium. Additional work on tearing modes, coupled to new transport model, is needed to improve the capability to predict plasma response to feedback control. Additional experimental data must be made available for construction of better transport models.

- Transport Processes in Divertor Scrape-Off - FY85

A recently formed Task Force on Plasma-Wall and Plasma-Divertor Interactions has been working on transport processes in divertor scrape-off regions. Atomic physics and kinetic approaches have been developed to study plasma transport in regions of low temperature and low density.

2. Mirror Theory

o Equilibrium, Stability and Transport in TMX - FY82

At the present time, the 3-D equilibrium calculations are being done for low beta in the long-term approximation. The form of the pressure is inferred from the distribution function in the appropriate sections of the tandem mirror. MHD stability is calculated on the basis of infinite mode number ballooning theory. Low-frequency kinetic theory indicates that higher betas are possible than the ballooning theory predicts. Work in FY82 will include extension of ballooning mode theory to large, but finite, mode numbers and work will be done in iterative use of MHD and Fokker-Planck codes to obtain self-consistent equilibria. 3-D codes may be required to study low mode number stability. Ion-ion collision effects on the LH drift mode have been examined and found to be stabilizing.

Theory predicts that classical resonant transport in tandem mirrors and cells is much greater than standard neoclassical diffusion. Experimental data show, however, that the ion flux in TMX is greater than predicted by resonant transport. Observations indicate that Alfven Ion Cyclotron nstability may be present, while the Drift Cyclotron Loss Cone mode may be suppressed. Low-frequency single-mode nonlinear microinstability analysis has been performed on the Russian PR-6 data and the results are in good agreement. However, further examination of resonance diffusion is required. Contribution of like particle collisions to transport was examined in the case of ion-ion collision effects on the LH drift mode and these collisions were found to be stabilizing. Further work will be done on the effect of transport of other microinstabilities such as ion drift and two-stream instabilities. Convective modes from the end cells to the center and rotational instabilities will also be investigated. These modes are observed in TMX, and successful prediction of reactor confinement requires understanding of how the modes scale to those conditions.

3. Alternate Concepts Theory

o EBT Ring Physics - FY82

The milestone is nearing completion. Ring-core stability criteria have been developed and verified with experimental data which predict maximum core beta. Studies have been performed of energy loss mechanisms for both ion and electron rings. These include electron synchrotron radiation and electron-electron and electron-ion collisions. Start-up and heating of the rings have been modeled by means of

Fokker-Planck codes. Both adiabatic and non-adiabatic motion of ring electrons has been modeled by particle tracking codes.

Power absorption by the ring is understood well enough to enable a large increase in stored energy by means of multiple frequency RF heating. Ring temperature scaling has been derived on the basis of experimental data. The scaling shows that temperatures in the ring increase with magnetic field strength (and equivalently with ECH frequency) as well as magnetic field scale length. The scaling law is of the form $\rho/L = 5 \times 10^{-2}$ where ρ is the hot electron relativistic gyroradius and L is the magnetic scale length. Interaction of this ring with the rest of the plasma is only partially understood at this time and must await the completion of the milestone entitled Equilibrium, Stability and Transport in EBT.

- Equilibrium, Stability and Transport in EBT - FY85

2-D and 3-D equilibrium codes have been in existence for several years that permit one to calculate flux surfaces and field lines in EBT. An equilibrium model has been developed such that numerically computed equilibria can be used as input into a ray tracing code designed to follow the propagation of RF waves in the plasma.

Stability has received a great deal of emphasis in the past year. A localized three-species Vlasov dispersion relation that includes low frequency core interchange modes and high frequency hot electron interchange modes has been developed and analyzed. Cyclotron harmonic effects are also included in the model. These studies have resulted in substantial modifications to earlier calculations that generally assumed some degree of decoupling between the hot electrons and core plasma. Certain microinstabilities have also been investigated.

The radial transport model has now evolved to a 1½-D code in which equations have been averaged along field lines using a self-consistent, 2-D, finite beta equilibrium with anisotrophic electron ring pressure. Radial transport solutions were obtained, which include the reversed magnetic gradient regions. The global confinement properties obtained on the basis of these calculations are similar to those previously obtained by means of 1-D calculations, but the profiles are somewhat different. The ambipolar potential profile has been calculated and has the same shape as is observed experimentally. An ad hoc high energy tail was included in the neoclassical transport theory. The additional ion flux due to the tail was found to increase the ambipolar potential and, in turn, increase the bulk ion temperature. However, the increase was not sufficient to account for the experimentally observed potential, nor for the potential predicted by the 1-D code. Work has begun on a 2-D kinetic model for the ion distribution that includes pitch angle effects. Particle orbits in EBT are now calculated with a fully relativistic Lorentz force equation code and a guiding center code that makes use of realistic magnetic field. The use of these codes has led to the development of a symmetrizing coil concept which promises to greatly enhance particle confinement in EBT-P size devices.

- Initiate 3-D Studies of Torsatron - FY80 Decision Milestone

The milestone is completed. 3-D studies of the torsatron were intiated in 1978 and completed in 1979. A full report with a proposal to build the device was submitted by MIT to OFE in March of 1979. 3-D computer studies were made to map out magnetic topologies at three different configurations: $\ell = 4$, $\ell = 2$, and a combination of the two. The effect of a compensating coil system capable of generating a variable vertical magnetic field was also studied. Such a system provides a maximum parameter range possible with regard to rotational transform and shear profiles, magnetic well depth and shaping of flux surfaces. The coils were designed to be in force-free configuration. The studies included equilibrium of the plasma which requires the calculation of flux surfaces and beta stability. High energy particle confinement was studied by means of computing particle orbits in an idealized vacuum configuration. A decision was reached by the contractor that sufficient information was available to construct a proof-of-principle torsatron experiment with a major radius of 2.06m and average plasma radius of 0.22m. The project was not approved due to lack of funds.

- Develop Stability Theory of the Spheromak - FY83

- Equilibrium, Stability and Transport of Field Reversed Configurations - FY85

Both of these milestones refer to theory of compact toroids. The spheromak grew out of the tokamak program; field reversed configurations were developed in the mirror and theta-pinch programs. Now they are considered to be variants of one class of device: the compact toroid. Compact toroids may or may not have toroidal magnetic fields. They may or may not have energetic ions to aid stability.

The stability theory of the spheromak is only partly developed, but has already been applied to aid the experiments. The most dangerous instability is the ideal m = 1 mode, which grows very rapidly. It is responsible for tilting the spheromak or for shifting it axially, and it can be stabilized by nearby conducting walls. Without conducting walls, every spheromak is unstable to this mode; this prediction has been confirmed experimentally. Theoretical study of this mode showed that it could be stabilized by a passive figure-eight conductor. This technique has already been demonstrated experimentally and may lead to practical stability control. Experiments at LLNL, LANL, and PPPL and the University of Maryland have verified in detail the effect of conductor shape on tilting and shifting modes.

Internal ideal modes set further limits on spheromak shape, current distribution, and beta. It is presently believed that all large scale ideal modes can be stabilized with a poloidal beta limit in the range of 30-60%.

Studies of resistive instabilities have been performed in straight geometry, ignoring toroidal effects. They show that the plasma can remain stable to these modes up to quite high beta, 25% or more. And if they saturate as in a tokamak they may be of no practical importance for confinement. Additional work is needed to include finite gyro-radius and other kinetic effects and to shift from straight to toroidal geometry.

Equilibrium, stability and transport of field reversed configurations is being studied at several institutions. The stability work discussed above is included under this. Equilibrium studies of these configurations have been completed, using analysis and 2-D codes. Modeling of the formation process showed several ways to improve the coils and circuit timing in experiments, and these predictions have been confirmed experimentally.

For the field reversed theta pinch, a particular problem has been the tendency for the plasma to spin-up and then become unstable. The onset of instability is understood theoretically in terms of rotation velocity and ion gyroradius, but there are two possible explanations for the cause of the initial rotation. These lead to different predictions of plasma lifetime in larger experiments. Theoretical and experimental work is continuing to determine which phenomenon is responsible for spin-up.

Transport in field reversed configurations is much less developed. Codes exist which couple 2-D equilibrium to 1-D transport for compact toroids. The transport includes classical transport coefficients, neutral beam injection, and impurity radiation loss. In experiments dominated by impurity radiation, calculations can be made to agree well with measurements. However, it is known that magnetic flux diffusion in compact toroids is not classical, especially for configurations with toroidal field. In these experiments the flux relaxes on a fast time scale to a minimum-energy "Taylor" state and there is evidence for a dynamo action which converts poloidal flux into toroidal flux. Although intense theoretical analysis has already shown qualitatively how these related phenomena occur through turbulent processes, understanding has not advanced to the point where expressions are available for the resultant magnetic flux, energy, and particle transport. Theoretical work continues in this area.

- Develop Transport Models for the Spheromak - FY84

The studies of transport are based at this point largely on available tokamak transport modules. A 2-D MHD equilibrium code has been written to calculate magnetic surfaces. These are fed into a fully 2-D transport code. The reason for the 2-D rather than 1-D nature of the code is that the most interesting transport occurs in the formation stages of the spheromak when the topology is changing. For the present experiments the most important terms in the transport equation are radiation due to carbon and oxygen. The use of coronal equilibrium is completely unjustified because of the time-scales involved. Radiation losses are underestimated by as much as two orders of magnitude. A time-dependent radiation model is under development. This model will keep track of all radiation states. This work is being done in cooperation with the spectrosopists.

Collisional transport regimes have been studied. In the Pfirsch-Schlueter regime toroidal effects are not important. In collisionless regimes, on the other hand, particle trajectories are very complicated and many types of trapped particles exist. The study of these and of their effect on transport has not yet been done. A new neutral gas module has been incorporated into the 2-D spheromak transport code. Its use will improve the predictive capability of the code in appropriate regimes, since there is a great deal of neutral gas present in the spheromaks of the present generation in which temperatures reach about 50 eV.

- Problems of Alternate Fusion Fuels - FY85

Advanced or alternate fuel cycles can be divided into deuterium-based (d - d, d - ^3H_e, d - ^6L_i) and proton-based (p - ^{11}B, p - ^6L_i). The deuterium cycles are simpler and more easily attained. They require moderate ion temperatures and produce significantly lower neutron fluxes and tritium recovery than does D-T. No tritium breeding is required.

Significant achievements have been attained. The physics problems associated with $d - d$ and $d - {}^3H_e$ have been scoped out. Synchrotron losses in specific geometries must still be calculated. Tools for calculating synchrotron losses in toroidal geometries have been developed, including the capability of calculating opacities. Many calculations have been carried out on $d - d$ and $d - {}^3H_e$ in advanced tokamaks. These show that tokamaks could burn these fuels if betas of 12 to 15% could be achieved. Preliminary studies also indicate that a tandem mirror device or a reversed field Z-pinch may well be suited to advanced deuterium cycle application. These conclusions are based on new values of reactivity which are a factor of two higher than previously believed. New calculations of reactivity take into account enhanced energy tails of the distribution function. These tails could be due to collisional effects of the reaction products, preferential heating of high energy particles, or microinstabilities. Reactor studies for $d - d$ and $d - {}^3H_e$ tokamaks have been carried out at MIT and Argonne National Laboratory. Some of these preliminary designs lead to very compact devices with moderate auxiliary heating, if high magnetic fields are used.

4. Generic Theory

   - Utilization of Parallel Processors for Fusion Problems - FY82

This milestone is completed. The computer, CRAY-1, based on parallel processor technology, was installed in 1978 and has operated without problems since that time. It was estimated that the complete conversion of all large fusion plasma modeling codes would take as long as three years to accomplish. Debugging and optimization were expected to take another year. One must keep in mind that several of these codes took many man-years to build and have been highly tuned to the idiosyncrasies of the only computer available to the community at that time, the CDC 7600. Since these codes were in heavy production use, diverting significant amounts of time for conversion and debugging did not seem likely. The conversion was done much more rapidly than projected for two reasons. The first was the complete saturation of the CDC 7600 computer, which provided enormous pressure on the code builders and code users to convert their codes to the CRAY. Still, the conversion effort would not have been accomplished as rapidly as it was had it not been for the foresight and high competence of the staff of the NMFECC, who developed their own operating system for the CRAY. This system, CTSS, is not only superior to the manufacturer-supplied operating system, but it also retains most of the desirable features of the CDC 7600 operating system developed at Livermore. This made the conversion much easier and much more rapid. At the present time, all of the core- and CPU-intensive codes in the fusion program can be run on the CRAY.

- Development of Realistic Anomalous Transport Models - FY84

Particle or energy transport across a magnetic field can arise from either magnetic or electric fluctuations. Both magnetic and field fluctuations have been measured on tokamaks. The goal of anomalous transport theory is to identify the source of fluctuations, explain the observed amplitudes and spectra and calculate particle and energy transport rates. The presently available theoretical transport rates are two orders of magnitude too small to explain the observed confinement time. Possible sources of magnetic fluctuations are microtearing modes, finite-beta drift waves and rippling modes. The linearly unstable spectrum of microtearing modes should depend on plasma density, yet experimental observations show that the spectrum is insensitive to density. The study of the linear theory of this instability is not complete. The effects of toroidal geometry are only partially understood. An investigation of the saturation and transport associated with the nonlinear development of the microtearing mode has been carried out in nonsheared magnetic fields. The resulting fluctuation levels are consistent with experimental observations. The observed spectrum, however, has not yet been explained. The apparent absence of correlation between the density and magnetic fluctuations in the experiments may preclude finite-beta drift waves as a source of these fluctuations. The possible role of rippling modes in producing magnetic fluctuations is still under investigation.

Most of the theoretical work on tokamak transport has been devoted to the drift wave, from collisional through collisionless regimes. Linear theory of drift waves is, in general, fairly well understood. Current research is therefore devoted to the development of models to describe the nonlinear behavior and the associated particle transport. A complete nonlinear theory of drift waves must explain the amplitude of the density fluctuations, the shift of the spectrum towards long wavelengths and the broad frequency spectra. A major limitation of previous nonlinear studies of drift wave turbulence has been the nearly complete neglect of magnetic shear. Recent work has shown the importance of shear in stabilizing the drift modes. Future work will include the development of a fluid code to simulate drift modes and transport in tokamaks. Such a code, even though it would not be able to treat trapped electrons, would make it possible to treat more realistic parameters.

A realization has emerged in the community from reviews of this subject that there is need for close interaction between theory and experiment if this very difficult problem is to be solved. Impressive progress has been made in theoretical models of turbulence and improved fluctuation measurements. It is not clear at this point whether a theory of plasma turbulence from first principles will ever be developed. Such a theory in hydrodynamics has eluded researchers for over a century. But empirical formulas exist in hydrodynamics that permit accurate prediction of behavior of hydrodynamic systems. Close cooperation between theory and experiment will provide the necessary basis for such an empirical approach.

o Effects of Impurities in Fusion Plasmas - FY84

This is a broad category of studies that include transport theory, materials and atomic physics. The effort in atomic physics has been supported for the last eight years to obtain rates for impact excitation and ionization, dielectronic recombination, charge-exchange and radiation. In tokamaks, in the recent past, research has concentrated on heavy metals and radiative losses caused by their presence in the plasma. Among these are tungsten and molybdenum. These data are used as input into impurity transport codes to calculate the transport of impurities and their effect on temperature and density profiles of the plasma through radiation cooling.

Materials science is used to construct models of impurity production by vessel walls as well as absorption and recycling of impurities already present in the plasma. The density, ionization levels, and recycling rates of different atomic species of impurities have a crucial effect on the temperature of the outer regions of the plasma. This determines the diameter of the plasma column and, in turn, the energy confinement time in tokamaks. A Task Force on Plasma-Wall and Plasma-Divertor Interactions has been formed from various national laboratory and university components. The Task Force is examining a broad range of problems associated with plasma and impurity flow in divertor chambers, impurity production and recycling and the effect on atomic processes in impurities in the outer regions of the plasma where densities and temperatures are low and kinetic treatment is often necessary to look at the behavior of impurities.

The work in this broad area is expected to continue and theory will iterate with confinement experiments as new data from PDX and ISX-B in impurity control becomes available. Efforts will continue in the use of impurities for space-resolved measurements of ion temperature in tokamaks. Additional work in atomic physics on impurities such as argon will be done to support impurity transport studies in which a noble gas is puffed into the plasma and its transport is followed by spectroscopic means.

V. APP Directions

The elements of the Applied Plasma Physics activity are integral parts of the physics effort within the fusion program. Those elements are redirected as the directions of the physics program are changed. Perhaps some concrete examples would be useful. New initiatives in the physics program in recent years have included: the tandem mirror which led to fabrication of TMX, MFTF-B, and TARA; acceleration of the EBT concept and initiation of EBT-P; advanced toroidal systems to provide steady-state operation and other desirable reactor features; and the FED design activity.

A large part (65%) of the theory program is located at the site of major experimental programs and provides closely coupled support to the experiments. In fact, the physics design for new devices such as MFTF-B, TMX-U, and EBT-P and a significant amount of data interpretation are done by the theorists. Therefore, the theoretical activities in our large laboratories are redirected as the directions of their experimental programs change. Theory projects at universities and other off-site locations have been redirected to provide answers to critical problems for the program's new initiatives such as the tandem mirror, EBT-P and FED. There has been a very substantial theory contribution to the FED design by many contractors supported for tokamak theory work.

In the National Magnetic Fusion Energy Computer Network activity, computer time is provided to all parts of the fusion program, and computer time is allocated annually using an internal review process which involves all divisions in the Office of Fusion Energy. Requests for computer time from OFE contractors provide the same level of justification and receive the same level of scrutiny as requests for funds. Requests for computer time have always exceeded the time available, resulting in a hard examination of program priorities. Consequently, through this process computer time allocations have been shifted to reflect program priorities not only for the physics program but for the technology program as well. The second Class VI computer was added to the network in FY81, not only to improve and increase physics modeling and data analysis but to satisfy some of the needs of the engineers, such as the use of stress analysis codes which consumes substantial amounts of time. In addition, a small amount of time is held by the Office of Fusion Energy as a high priority reserve which can be shifted from contractor to contractor to cover emergency high priority needs above their normal allocation. This reserve has been used to cover such problems as EBT-P and FED design work.

The Experimental Plasma Research activity supports a variety of essential experimental research, much of which is performed by universities. A key feature of this activity is that most of the experiments are performed on small devices which provide the fusion program with the flexibility to test new ideas quickly at a low cost. Although these devices are smaller than the large confinement devices, they still produce energetic ($T \gtrsim 100$ eV, $N \sim 10^{13}\mathrm{cm}^{-3}$) plasmas and provide a good early test of an idea which, if successful, is then transferred to a large device for a more significant test. Also, it is often possible to obtain more detailed physics information from the smaller experiments. The answer to Question #10 provides a case study of lower hybrid current drive which illustrates this process.

Further examples are redirection of work at MIT, the University of California at Irvine and Los Angeles to study problems important to tandem mirror operation such as thermal barrier physics and stability issues. A new program was initiated on TEXT to study energy and particle confinement to improve our understanding of this important phenomena and to improve our predictive capability for design of FED. A significant part of the diagnostic development efforts has been focussed on the measurement of current density profiles in tokamaks, critical to the understanding of beta limits and other phenomena. Atomic physics measurements are continually redirected to obtain data on atomic processes which are of immediate concern in experiments.

The Advanced Fusion Concepts activity has been focussed substantially over a period of several years. This focussing was done only after a systematic evaluation of a number of fusion concepts. The major remaining programs are the reversed field pinch and compact toroids. Support at lower levels is also provided for an alternate fuel assessment (see Question #6) and torsatrons. The support for torsatron research is modest and allows the U.S. program to keep abreast of the very encouraging results being obtained in Europe and Japan. During this process of focussing research, a number of concepts including the laser heated solenoid, TORMAC, LINUS, imploding liners, and linear theta pinches has been terminated.

6. What are the detailed FY80, FY81, FY82, and FY83 funding levels for advanced fuel assessment? What was accomplished in FY80 and FY81 and what are the planned accomplishments for FY82 and FY83? Please provide a detailed justification of how this program and the efforts funded by this program support the stated objectives of the Advanced Fusion Concepts subactivity?

The current Office of Fusion Energy program emphasizes deuterium-tritium (D-T) fuel cycle reactors, because D-T is by far the most easily burned fuel and the one closest to realization. Notwithstanding these considerable assets, it carries difficulties associated with the need to breed tritium and radioactivity caused by copious fluxes of energetic neutrons. While the radiological hazards from D-T reactors are greatly reduced when compared with those from nuclear fission plants, it is prudent to have a vigorous alternate fuel program which offers the possibility of further reducing radiological and environmental problems. At a minimum, such a program would establish the potential of alternate fuels on a time scale that makes the knowledge available if the enviromental, safety and licensing aspects of D-T reactors turn out to be serious.

Potentially, alternate fuels offer real economic advantages over D-T in addition to environmental acceptability. These advantages include the elimination of tritium breeding, removal of a large quantity of highly chemically reactive lithium, reduced tritium handling, lower induced radioactivity, improved maintenance potential, high efficiency energy conversion, etc. The OFE assessment of alternate fusion fuels strives to quantify these advantages.

The alternate fuel assessment which is presently scheduled for completion by the end of FY83 is supported throughout the Office of Fusion Energy with relevant components within the subprograms of the Development and Technology (D&T), Mirror (MCS), and Toroidal (TCS) Confinement Systems Divisions and the Fusion Theory Branch in addition to the Advanced Fusion Concepts (AFC) Branch of the Applied Plasma Physics (APP) Division. The role of the Advanced Fusion Concepts Branch has been to coordinate the interdisciplinary efforts throughout the fusion program, and to contribute to those parts of the study that are specific to its development of Advanced Fusion Concepts, such as reversed field pinches, etc. (Please refer to the description of the AFC program in the response to Question #5, above.)

The purpose of the activity is to conduct a quantitative evaluation of the potential contributions to alternate fusion fuel cycles to the ultimate potential of fusion power systems, and further to contribute to the assessment of the optimum fuel cycle at this stage of fusion power development. This is consistent with the requirements of the Magnetic Fusion Energy Engineering Act of 1980.

The approach is to undertake in parallel, and to the degree allowed by program funding, quantitative assessments of the physics, technology, engineering and user advantages and disadvantages of alternate fuel cycle fusion power plants. A staged study is being pursued in which the deuterium-deuterium (D-D) fuel cycle is being assessed initially, and the (possibly) more attractive and demanding fuel cycles such as p-^{11}B will be undertaken subsequently.

The detailed FY80, FY81, and FY82 funding levels are tabulated below:

	FY 1980	FY 1981	FY 1982
Advanced Fusion Concepts	$ 0	$ 210,000	$ 280,000
Fusion Theory	0	170,000	150,000
Mirror Confinement Systems	0	0	120,000
Toroidal Confinement Systems	0	100,000	50,000
Development and Technology	0	0	0
Totals	$ 0	$ 480,000	$ 600,000

Accomplishments in FY80 were confined to the program review and analysis required in OFE to prepare for the three year assessment.

Accomplishments in FY81 include:

- Tokamak reactor simulation codes have been modified to handle deuterium based fuel cycles (d(d,t)p, d(d,^{3}He)n, d(t,α),p).
- Initial applications have been to the Argonne National Laboratory DD-Tokamak reference design.
- A deuterium based code has been adapted to include multispecies burn, slowing down, banana confinement of reaction products and a new synchrotron radiation routine has been incorporated.
- Fusion cross section data have been assembled, averaged and incorporated into the deuterium based code.
- Transport coefficients utilized are being updated.
- Codes have been improved to include 2-D equilibrium and MHD stability.
- The fast cylindrical synchrotron radiation transport code has been fully developed, documented and made available on the MFE network.
- Codes have been used to analyze start-up, refueling, and recycling scenarios.
- Tokamak physics and engineering studies using 0-D codes for parameter surveys, 1½-D for tokamak simulations have been started, technology requirements examined, and assessment of D-D tokamak related to D-T designs has begun.
- A reactor attractiveness method has been developed to assess the engineering and operational attractiveness of various reactor concepts in comparison with their D-T counterparts.

- Preliminary evaluations of technology and required R&D for the tokamak and the reverse field pinch have begun.
- Development and application of a deuterium based RFP code was begun.
- Background studies for an EBT deuterium based reactor are near completion.
- Deuterium based EBT code development has begun.
- Deuterium based axisymmetric tandem mirror code development has begun.

Planned accomplishments for FY82 include:

- Complete D-D tokamak reactor systems analysis, reactor assessment, and R&D needs assessment.
- Complete the D-D tandem mirror physics and code development (include equilibrium and stability), initiate engineering analysis and trade off studies of D-D tandem mirror reactor systems, identify a satisfactory D-D tandem mirror reactor design, and initiate an assessment of this design.
- Conduct technical workshops (at least two) on pertinent alternate fuel issues to be identified during the course of the work.

Planned activities for FY83 include:

- Complete the D-D tandem mirror reactor systems analysis, the reactor assessment, and the R&D needs assessment.
- Complete the RFP physics development, the D-D reactor assessment, and the R&D needs assessment.
- Undertake and complete the D-D EBT physics and code development, initiate engineering analysis and trade-off studies of D-D EBT reactor systems, identify a satisfactory D-D EBT reactor design, and initiate an assessment of this design.
- Prepare an analysis of the prospects of the proton fuel cycle system based on a reactor systems analysis, and reactor assessments.
- Conduct technical workshops on pertinent issues that are identified during the course of the work.

Major milestones include:

Complete initial version of D-D tandem mirror simulation code	March 1982
Complete D-D tokamak Reactor Assessment Report	May 1982
Complete R&D Needs Assessment for D-D tokamak	Sept. 1982
Complete documentation of plasma physics simulation code for D-D tandem mirror	June 1982
Identify a satisfactory D-D tandem mirror reactor design in conjunction with LLNL	July 1982
Complete Physics Assessment of D-D tandem mirror	Sept. 1982
Complete technology assessment and requirements for D-D tandem mirror reactor	Sept. 1982
Complete D-D tandem mirror reactor assessment report	Dec. 1982
Complete D-D RFP physics assessment	Sept. 1982
Establish operating point for D-D RFP	Sept. 1982
Complete review of existing D-D RFP reactor design	Sept. 1982
Complete D-D RFP Reactor Assessment Report	March 1983
Identify a satisfactory D-D EBT reactor design in conjunction with ORNL	April 1983
Complete D-D EBT Reactor Assessment Report	Oct. 1983

7. Has any analysis been done or the possibility and/or feasibility of establishing at least nominal user fees for th MFE Computer Network? If not, why not? How many users during the last 3 fisc l years were not funded by OFE when they used the Network?

The present process for cont olling computer usage has evolved over several years, and it is considered o be optimum for the fusion program as presently constituted. Allocat on of computer time is made only to organizations having a contractual r lationship with OFE. Thus, there have been no organizations during the las three fiscal years which used the network without such a contractual r lationship.

The process of allocating co puter time is analogous to that of allocating funding. Contractors submit proposals for computer time (termed Decision Packages) which detail the p ogrammatic purposes, the computational techniques to be employed and th amount of time required. These are scrutinized by contract monitors an then weighed in competition with all other requests by the computer res urces committee, consisting of representatives from all divisions of OFE. his ensures that allocated time is used to best satisfy programmatic ne ds as constrained by the available resources. By division, the present all cations include about 45 percent Applied Plasma Physics, 40 percent C nfinement Systems, and 15 percent Development and Technology.

The advantages of this proce s include the following:

1. Computation is controll d directly so that better funded contractors cannot do marginal comp ting simply because they have funding.

2. Small contracts with le itimate need for computing are not squeezed out by better funded co petitors.

3. Over-saturation of comp ting resources by unplanned demand of contractors for c ute time is avoided. Total allocations never exceed available resour es.

4. Determination of future requirements for computing is aided by analysis of decision pa kages. These are also used to determine needs for specialized codes f other network services.

5. Rapid accommodation of nexpected critical computing is possible by direct adjustment of al ocation.

We consider that the disadva tages of computer charges presently outweigh the advantages. These disad antages include:

1. Inability to avoid dele rious consequences of temporary over or under demand for services. L g lead time for government acquisition of computing resources mea s that money cannot freely be converted into suitable computing time

2. Inability of contractors to plan on availability of computing resources due to competition from other contractors.

3. A non-cost effective flow of money simply from one pocket within the fusion program to another, accompanied by extra bookkeeping costs.

4. Loss of visibility of computing, which presently results from Decision Package process.

5. Loss of ability by OFE to insure resource sharing of computing for benefit of entire fusion program.

8. For each current or planned facility supported and/or operated by OFE (e.g., Alcator C, ISX, PLT, TARA, etc.), please provide a detailed explanation of the uniqueness of each machine and how each will be used to provide the answers needed to further the FED design effort.

As is explained elsewhere (e.g., see answer to Question #12), both physics research and engineering are being pursued in parallel toward the goal of developing commercially attractive fusion power. The status and capability of each major planned and operating confinement facility are outlined in the accompanying Tables 8-1 and 8-2. In general, each tokamak confinement device contributes to FED issues as well as to issues pertaining to optimization of tokamak-like reactors. Table 8-1 indicates how each tokamak device is expected to contribute to the physics and the engineering design of the FED.

The mirror program, which is comprised of the tandem mirror and the Elmo Bumpy Torus efforts, is intended to develop superior reactor confinement configurations and is consequently much less oriented toward resolving specific tokamak FED issues. Because of the interconnected nature of the fusion program, however, such contributions do occur. The use of ECRH and high power gyrotrons, whose development has been driven by program requirements of the Elmo Bumpy Torus, is a good example of this. Table 8-2 shows how each mirror confinement device is expected to contribute to relevant physics issues.

Table 8-1

Toroidal Program Matrix

			PLT	PDX	D-III	ISX-B	ALC C	TFTR	D-III DEE	ATF	
Status			Operating	Operating	Operating	Operating	Operating	Under Construction	Planned	Planned	
Unique Capability			ICRF Current Drive	Impurity Control	Low q Shaped Plasmas	High β	High Field High Density	Breakeven DT Plasmas	FED Plasma Engineering	Toroidal Optimization	
Physics Issue	Tokamak FED Issue	Advanced Toroidal Issue									
Heating & Current Drive	ICRF Non OH Start-Up		2.0 MW ICRF, LH Current Drive						FED Prototype		
		Steady State, Best Heating Method		ECH (Physics)	ECH (High Power)		LH Current Drive at High N			Steady State Demonstration	
Fueling	Pellet Fueling			Four Pellet Injector		High Velocity Injector					
		Same as for FED									
Equilibrium & Stability	$\beta \cong 5\%$ Disruption Control				Low q Shape Optimization	2.5% β, Circular Shape			FED Prototype		
		Higher β Values								High β, Disruption Free	
Perpendicular Transport	Minimum Size for Q = 6		Transport at High Temp				Transport at High Density	Major Size, Temp. Scaling			
		Minimum Size for Ignition								Improved Confinement	
Impurity Influx	Mechanical Vs. Magnetic Divertor			Optimized Magnetic Divertor	Expanded Boundary				FED Prototype		
		Optimized Control Method								Optimized Impurity Control Method	
Self Heating	α Particle Heating		Simulation With Beams					Study α Particle Deposition			
		Same as for FED									
Electric Potential	Thought to Have Some Effect on Transport					Exp. to Meas. El. Pot. Planned					
		Same as for FED									
Parallel Electron Transport	Not a Tokamak Issue										
		Not a Toroidal Issue									

Table 8-2

Mirror Program Matrix

		TMX-U	Phaedrus	STM	MFTF-B	TARA	EBT-S	EBT-P
Status		Checkout	Operating	Operating	Under Construction	Construction About to Start	Operating	In Design
Unique Capability		Thermal Barriers	R.F. Tests	Hot Electron Stabilization	Breakeven Conditions	Axisymmetry	Only Bumpy Torus in U.S.	Proof of Principal Test
Physics Issue	Concept Improvement Issue							
Heating	Steady-State R.F. & Beams		ICRH Research	ECRH Research	High Power Heating	Neutral Beam Design	Steady-State ECRH	High Frequency S.S. ECRH
Fueling	Pellet Injection/ Radial Diffusion or Axial Trapping		Axial R.F. Trapping		Radial & Axial			Pellets, Radial
Equil. Stability	Axisymmetry Beta Limits Loss Cone Mode	Microstable End Cells		MHD Stability by Rings		Average Minimum B		Test Beta Limits
Perpendicular Transport		First Measurements			Major Scaling Experiment	Test Axisymmetry Effect		Major Test
Impurity Control	Not a Problem So Far	Test "Self-Divertor" Action					Divertor Test	Major Test
Self-Heating	Alpha Particles				Particle Simulations Planned			
Electric Potential	Tandom Mirrors Axial E; EBT-Radial E	Thermal Barrier Tests	Axial Measurement		Radial, Axial Profile Studies		Radial Profiles	Detailed Studies Planned
Parallel Elec. Transport	End Loss From Open Systems	End Loss Reduction by Thermal Barriers			Major Scaling Experiment			

9. In the December 16 briefing, eight fusion physics issues were delineated (heating, fueling, MHD equilibrium and stability, etc.). Which of these are critical to the design, construction, and operation of the FED? What OFE activities are underway or planned to address each of the critical issues? Identify these by subactivity, e.g., D&T, APP, etc.

Tables 8-1 and 8-2 accompanying Question #8 list the eight physics issues discussed and show that six of them are critical to the design, construction, and operation of a tokamak-based FED. Also shown are the OFE experimental programs which are expected to address and resolve each of these FED design issues.

Three OFE divisions work closely together to optimize the physics and engineering output from these key fusion programs.

The Toroidal Confinement Systems Division has direct responsibility for operation of the tokamak-like experimental devices. The experimental programs, however, depend heavily upon the Development and Technology Division which, while having no direct physics related responsibility, does have the responsibility for developing the technological systems necessary to produce the reactor grade plasmas which are required to address the physics issues. For example, the ORNL Heating Technology Group constructed the neutral beam systems which are used to heat the PLT, ISX and PDX plasmas to reactor temperatures.

The Applied Plasma Physics Division pursues a general plasma theory and experimental program, and directly supports confinement systems experiments. It does so by building the large two and three dimensional codes which are necessary to extract the basic physical quantities (e.g., the heat conductivity) from the experimental data, and by interpreting the measured physical quantities in terms of the basic underlying plasma processes. APP also supports the development of plasma diagnostics used on all the major confinement systems devices (TEXT is a facility built especially for such development) and a number of smaller tokamaks on which basic physics programs are conducted in support of the larger confinement devices.

The APP activities are described in the answers to Questions #5 and #10. Those activities that are particularly relevant to the FED are in the areas of Heating and Current Drive (MICROTOR/MACROTOR, TEXT, Versator, Cal Tech, Theory), Equilibrium and Stability (TORUS II, magnetic field diagnostics theory), Perpendicular Transport (TEXT, Far IR diagnostics, theory), Impurity Influx (Hot Wall and pumped limiter work on MICROTOR, Impurity Transport Theory) and Electric Potentials (ion beam diagnostics and probe measurements at Cal Tech).

10. Using the current drive achievements outlined in the 12/16/81 briefing, provide estimates for the durations of time and costs involved in performing the studies that led to the PLT and Versator results. Include data from the relevant work of prior years.

A directed effort to utilize RF for tokamak current drive began in FY79. Prior work, especially theoretical analysis, provided a basis for the decisions that led to the directed program. A key theoretical contribution occurred in 1977 when scientists at MIT determined conditions for efficient utilization of the RF energy.

A workshop organized by OFE at Princeton in late FY78 identified the importance of steady state operation of tokamaks to overcome thermal and electrical load problems of pulsed operation. A direct result of that workshop was the implementation of steady state current drive experiments by APP at PPPL and MIT. The ACT facility at PPPL was diverted into current drive work in FY79 and FY80 at a total level of $800,000. This machine obtained the first direct and unambiguous current with RF energy after 12 months of effort, although at low power and low current (2 kA). The Versator experiment at MIT also began current drive work in FY79. Their first results were obtained in 15 months and their recent data is perhaps the best diagnosed and interpreted data on RF-driven current available. Over $1 million has been spent so far. Their results are at intermediate power and intermediate current levels (35 kA).

As the APP theoretical and experimental programs proceeded with promising results, the Confinement Systems program working with laboratory staff began in FY80 to plan RF current drive experiments at high power on Alcator and PLT. PLT obtained 230 kA for 500 ms in the summer of 1981 and Alcator C plans experiments in FY82. There has been close interaction between Alcator and PLT staff and the Versator staff on problems of the waveguide launcher design, on breakdown in the waveguide, and on power splitting. The Versator program has provided critical data on these problems. Ray tracing computer programs have been used to predict energy flow and power dissipation in all these experiments.

The current drive work has benefitted greatly from much larger projects on RF heating of plasmas. The RF energy and the experimental facilities (Versator, ACT, MACROTOR) were all available because of the RF heating projects, and most of the theoretical activity was also in place. The budgets listed here show the portion attributed only to the RF current drive part of the programs. As can be seen, theory is the major part of this program. This is because the theoretical program is studying the problem in a much broader context. While the experimental program is looking at the application of lower hybrid waves, theory is studying also conditions under which current can be driven at other RF frequencies, such as Alfven and ECRF. Furthermore, the theory is investigating nonlinear effects of wave propagation at high power densities, which is a subject of great importance in planned current drive experiments. Parallel electron transport is also being investigated since it determines the value of the density at which current drive cut-off occurs.

RF Current Drive Budgets (000's)

	1979	1980	1981	1982
ACT (PPPL)	400	400	-	-
VERSATOR (MIT)	350	345	350	475
ALCATOR (MIT)	-	30	30	35
PLT (PPPL)	150	150	350	500
Theory	470	545	640	670
Totals	1370	1470	1370	1680

11. Rank the technology accomplishments delineated in the 12/16/81 briefing charts according to their importance and criticality to the goal of achieving an EPR.

For this answer we have interpreted EPR as a post FED fusion machine. All of the areas listed in the FY81 technology accomplishment are important and most are critical to the goal of achieving a Demo, although the specific FY81 accomplishment itself may not be critical. With this background statement, those of higher importance are ranked above those of lesser importance. This list is only for FY81 accomplishments.

- Completed first draft of an integrated, comprehensive engineering development plan.
- Completed construction of Large Coil Test Facility vacuum vessel.
- Completed installation and initiated operation of isotope separation system for TSTA, with hydrogen and deuterium.
- Completed design and fabrication of capsule for solid in-pile tritium breeder test. (TRIO when installed)
- Identified and evaluated potential of radiation resistant organic insulator for magnets.
- Initiated construction of neutral beam engineering test facility at LBL.
- Completed measurement of helium production for 10 elements using 14 MeV neutrons in RTNS-II.
- Operated 28 GHz gyrotron at 342 kW continuously, and 60 GHz gyrotron at 200 kW for 10 millisecond pulses.
- Operated scale size 30 second neutral beam sources at LBL and ORNL.
- Operated 50,000 ampere superconducting cable at LANL.
- Operated 8T superconducting background coils in the High Field Test Facility at LLNL to lead to 12T.
- Selected lead contractors for the first wall, blanket and shield engineering test program.

12. Clarify the role of the FED as a major focus of the magnetic fusion energy program.

A. How will the applied plasma physics activities support the FED design, fabrication and implementation?

B. Which of the present generation devices support the FED project by providing critical design data?

C. How will these activities be coordinated from a management viewpoint?

The magnetic fusion energy program is seeking to achieve its goal of developing commercially attractive fusion power plants by pursuing in parallel an optimization of the plasma confinement configuration and the development of practical reactor engineering systems. Because fusion engineering systems are, in large part, generic to more than one fusion approach, our strategy is to continue the rapidly advancing studies of plasma confinement on several competitive lines while at the same time accelerating development of the required technology to take advantage of what we are learning on the physics side and turn it into practical use. The central mechanism for advancing the technology would be the Fusion Engineering Device (FED), to permit, for the first time, the production and handling of a significant amount of thermonuclear energy in an environment suitable for both individual component development and full systems integration tests. The FED role would thus be to serve as the major focus for the engineering side of fusion development, with physics development serving as the other major focus in the program.

A. How will the applied plasma physics activities support the FED design, fabrication and implementation?

Applied Plasma Physics has provided significant support to the FED design activity and is expected to continue to provide support through all phases of the project. The fusion theory activity contributes substantially to the physics design of all major fusion experiments and it also plays an important role in the interpretation of data from these experiments once they operate. The FED will be designed to operate with parameters beyond those previously achieved and consequently theoretical models will be essential for design and optimization. Much of this modeling will rely on large, complex computer codes which are continually being updated as improved theoretical models are developed and new experimental data are obtained. After FED becomes operational, the theory program will play an important role in analyzing the physics performance of the device.

Large amounts of computer time on the National Magnetic Fusion Energy Computer Network will be used for all phases of FED activity. The computers will be used extensively for physics as well as engineering design calculations. Analysis of data generated by the FED will also consume considerable amounts of computer time.

The Experimental Plasma Research activity will contribute to FED in three areas: initial testing of new ideas which will improve performance and/or lower cost, development of new diagnostics, and atomic data. For example, new ideas for improving FED such as steady-state current drive, improved RF heating and simplified impurity control techniques (pumped limiters) are now being tested on small devices. Some new diagnostic techniques will be required for a large hot FED plasma producing fusion reactions. For example, a diagnostic to measure the number density and energy distribution of alpha particles is needed. The long pulse or steady-state operation of the hot FED plasma makes impurity and neutral gas control an important design issue. Improved or new atomic data is required to provide more accurate modeling of these phenomena.

The Advanced Fusion Concepts activity is not expected to provide direct support for a tokamak based FED. The potential benefit to FED will come from studies of other (non-tokamak) toroidal confinement configurations which might lead to superior FED designs.

9. *Which of the present generation devices support the FED project by providing critical design data?*

There are two major technology facilities and a number of major plasma facilities which support the FED.

o Large Coil Program

The Large Coil Test Facility (LCTF) is part of the Large Coil Program (LCP) designed to test six large 8 Tesla superconducting coils now being built as part of an international program under an International Energy Agency cooperative agreement. The coils will be the largest 8 Tesla coils ever constructed in the world, and their operation and testing in the LCTF will establish the technological base in large superconducting coil development for future devices such as the Fusion Engineering Device.

Three of the coils are being built in the United States and one each by Euratom, Switzerland, and Japan.

This program is unique in both the size of the coils, the field strength of the coils and the international cooperation.

o Tritium Systems Test Assembly

The Tritium Systems Test Assembly (TSTA) is a prototype tritium handling and processing facility which will provide directly applicable design information for all tritium systems required for basic operation of FED. These include plasma exhaust, fuel cleanup, isotope separation, tritium transfer, storage, containment, and cleanup.

o Tokamak Devices

The relationship between the programs of each of the tokamak devices and the FED design issues is shown on Table 8-1 accompanying Question #8.

C. How will these activities be coordinated from a management viewpoint?

Because the FED activities involve each of the parts of the magnetic fusion energy program to some extent, and many significantly, the management coordination has been structured as follows. Each of the FED activities is the responsibility of one of the five Division Directors, who are the line officials charged with managing the various elements of the fusion program. An FED Executive Committee, chaired by the Deputy Associate Director for Fusion Energy, assisted by a full time Executive Secretary and including the five Division Directors as members, has responsibility for the program-wide coordination of all FED related efforts. Requests for changes in any ongoing activity for the purpose of improving the effectiveness of an FED activity are reviewed by this group before implementation by the responsible Division Director.

13. To assist the Committee in gaining a clearer understanding of the interrelationships of the various projects within MFE subactivities, the following information is requested.

A. Using the program flow chart shown on Page IV-6 (copy enclosed) of the January 1980 MFE program summary document as a guide, develop a critical path flow chart showing in more detail the critical tasks and interrelationships among the several key projects within each subactivity.

The program flow chart from page IV-5 of the January 1980 MFE Program Summary Document is out of date relative to the current detailed logic of the fusion program. An updated flow chart is provided in Figure 13-1. On a general, descriptive level, the program flow chart is an attempt to describe on a single page both the complex relationships among the four formal MFE program subactivities in the near term and the program's principal logic for the mid and long terms.

In the near term, the primary driving force in the program is the information derived from the plasma confinement experiments conducted by the Confinement Systems subactivity. These experimental results are reviewed and analyzed by the Applied Plasma Physics (APP) subactivity with the result being development of plasma physics theories and models to explain the experimental results and suggest directions for additional investigations. Based on this information, the APP subactivity initiates experimental work and theoretical investigations of alternate confinement concepts or on basic physics problem areas (see Question #10 for an example) and develops diagnostic instruments for use by the Confinement Systems subactivity. The Confinement Systems and APP subactivities, working in conjunction, provide the physics basis for the MFE program.

Based on the program's physics results and projections, the Development and Technology (D&T) subactivity develops components, systems and engineering technology for use in near and mid term fusion experiments and develops projections of the most likely nature of the fusion power reactors which will eventually be built. These fusion power reactor projections serve to identify component, system and technology developments which must be undertaken to prepare for the eventual commercialization of fusion.

In carrying out the assignments of the Confinement Systems, APP and D&T subactivities, needs for new facilities are identified from time to time which are classified as major system acquisition projects. The Planning and Projects (P&P) subactivity is responsible for carrying out these major system acquisitions, as well as for conducting general MFE program planning activities, including international initiatives.

To understand the current, long term, logic of the MFE program, it is more appropriate to refer to Figure 13-2. This Figure is a summary of the program logic information from Figure 13-1.

The first step in the overall, long term program logic is to demonstrate the scientific feasibility of fusion. This task is being undertaken by the four MFE subactivities acting in conjunction. The actual demonstration of fusion's scientific feasibility will be done in a facility called the Tokamak Fusion Test Reactor (TFTR) which was conceived by the Confinement Systems subactivity, based on the theories and plasma modeling developed by the APP subactivity. Since TFTR is a major systems acquisition, construction of the facility is being managed by the P&P subactivity, using technology developed by the D&T subactivity. TFTR will actually be operated by the Confinement Systems subactivity after it is completed.

The next steps after the demonstration of scientific feasibility will be to pursue the demonstration of the engineering feasibility of fusion and the development of a complete generic fusion engineering base, in parallel with efforts to improve the understanding of fusion physics to minimize the cost and improve the performance of needed future facilities, as well as to evolve a more nearly optimum reactor concept. Preparation for these steps must start in advance of the operation of TFTR to preclude a lengthy pause in the MFE program following demonstration of scientific feasibility.

The demonstration of the engineering feasibility of fusion will be carried out using facilities such as the Fusion Engineering Device (FED) and the Fusion Materials Irradiation Test (FMIT) facility. A complete description of the role to be played by the FED can be found in Volumes I and III of the FED document, DOE/TIC-11600. These facilities will be built as major system acquisitions with substantial help and involvement on the part of all of the MFE subactivities.

The continued improvement of fusion physics and evolution of a more nearly optimum fusion reactor concept will be accomplished through the use of facilities such as the Mirror Fusion Test Facility (MFTF-B), the Advanced Toroidal Facility (ATF), and possibly other smaller facilities not yet identified. This process of developing concepts to improve or replace the basic tokamak approach has been given the name of Alternate Concept Physics Test Program (ACPTP).

The engineering feasibility demonstration and physics optimization efforts will extend through roughly the next decade and will yield results whose nature cannot be confidently predicted, but which will determine the sequence of events to follow. We have accounted for this by indicating that an assessment of the progress made during the engineering feasibility demonstration and physics optimization steps will be conducted as soon as possible in the 1990's. This assessment will occur over a period of time as the results from the engineering and physics programs become firm. The expectation is that an improved plasma physics concept will evolve and a set of engineering techniques will be demonstrated with which the improved physics concept can be turned into a power producing fusion reactor. This device would be the Fusion Demonstration Reactor Plant, or Demo, mentioned in the overall program logic in Figure 13-2.

Figure 13-1

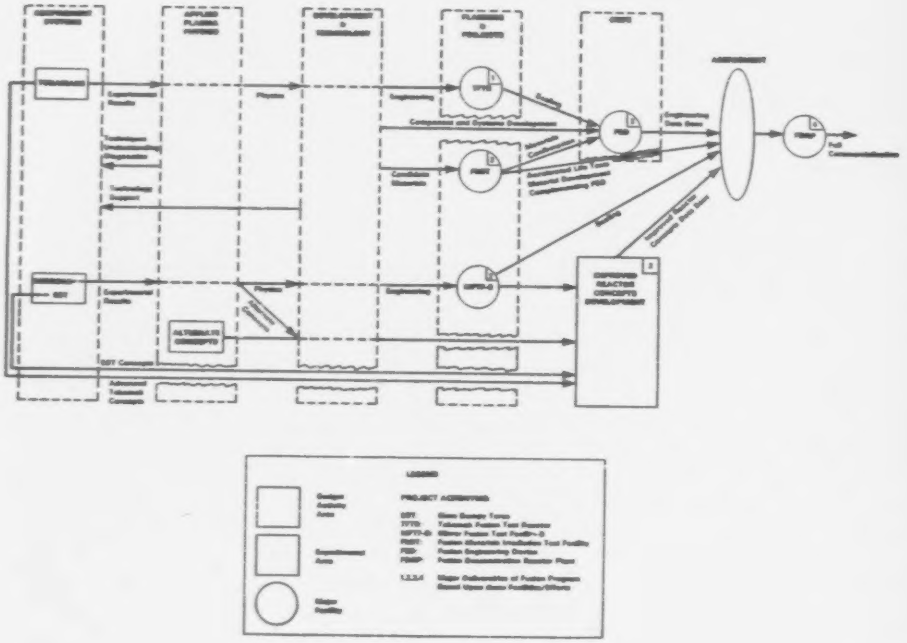
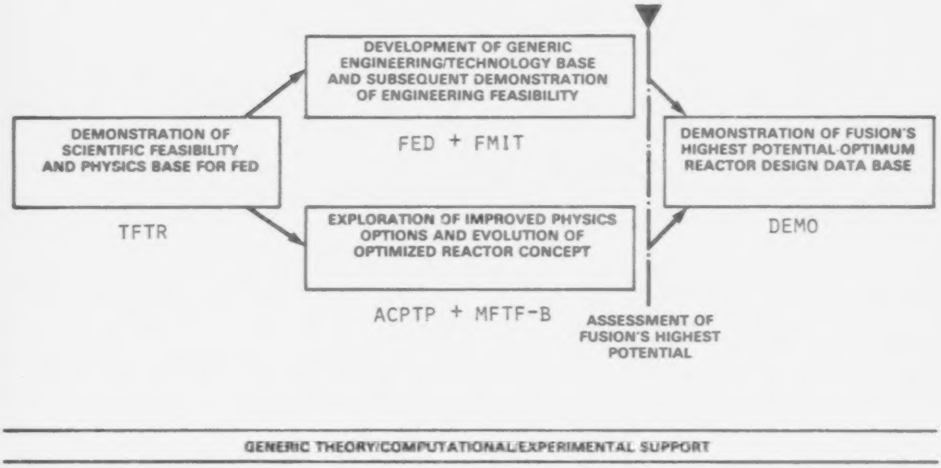

Experimental Results
Physics
Engineering
Components and Systems Development
Technology Support
Candidate Materials
Scaling
Engineering Data Base
ALTERNATE CONCEPTS
IMPROVED REACTOR CONCEPTS DEVELOPMENT
FED
1
2
3
4
Full Commercialization
LEGEND
Design Activity Area
Experimental Area
Major Facility
PROJECT ACRONYMS
TFTR: Tokamak Fusion Test Reactor
FMIT: Fusion Materials Irradiation Test Facility
FED: Fusion Engineering Device
1,2,3,4

Figure 13-2

OVERALL PROGRAM LOGIC


DEMONSTRATION OF SCIENTIFIC FEASIBILITY AND PHYSICS BASE FOR FED
TFTR
DEVELOPMENT OF GENERIC ENGINEERING/TECHNOLOGY BASE AND SUBSEQUENT DEMONSTRATION OF ENGINEERING FEASIBILITY
FED + FMIT
EXPLORATION OF IMPROVED PHYSICS OPTIONS AND EVOLUTION OF OPTIMIZED REACTOR CONCEPT
ACPTP + MFTF-B
ASSESSMENT OF FUSION'S HIGHEST POTENTIAL
DEMONSTRATION OF FUSION'S HIGHEST POTENTIAL-OPTIMUM REACTOR DESIGN DATA BASE
DEMO
GENERIC THEORY/COMPUTATIONAL/EXPERIMENTAL SUPPORT

14. In a meeting in January 1981 we were told that the TFTR was scheduled for operation (First Plasma) in August 1982. Later this date was slipped to December 1982. Is that date still valid? If not, how can it be restored?

The August 1982 date for TFTR operation (First Plasma) has been used in the past as an ambitious internal project milestone. In the June 23, 1981, letter to the Chairman, Committee on Science and Technology, from N. D. Pewitt, Acting Director of Energy Research, the Department acknowledged that attempts to improve upon the official First Plasma date of December 1982, which is identified in the fiscal year 1982 Congressional Budget, might not be possible. Currently, such improvements are not possible and the December 1982 date is now considered to be valid. While potential delays of one to two months beyond December 1982 have been forecast, the project team has, with some added risk, been able to compress the required time for critical assembly tasks and reschedule installation and test activities to eliminate these delays.

15. The TFTR was to become operational in 2 fundamental steps: Step 1 was to use hydrogen; step 2 operations was to be full D-T. As you know, scientific breakeven cannot be accomplished without D-T and the D-T operations were scheduled to follow the hydrogen by 2 years. This would mean D-T operations will occur around December 1984. Is this date still firm? Why do current plans call for 2 years of hydrogen operation?

The earliest date for starting TFTR D-T operations is currently being evaluated. However, there are four consecutive phases required before starting D-T operations, with each one building upon the achievements of the previous phase. The reasons for, and approximate time spans of, the hydrogen activities before D-T operations are the following: The first phase, about one year, consists of ohmic heating of progressively larger plasma currents. During this time, the basic plasma behavior and interactions between the plasma and the tokamak device are determined. The second phase, about six months, requiring as an initial condition full installation of beam systems, consists of neutral beam heating of progressively larger plasmas in order to qualify the operation of the beams and to understand the interaction between the beams and plasma. The third phase, about six months, consists of optimization of reliable operation of the facility hardware with all systems operational. This is an important phase in preparing for the safe and efficient conduct of D-T experiments. Scientific breakeven can be inferred from this phase from D-D reactions which can be performed without waiting for the introduction of tritium. The final phase, about six months, consists of plasma optimization in which full power TFTR operation is demonstrated just before introduction of tritium. This total time span following First Plasma is about 2½ to 3 years, at the end of which D-T experiments would begin.

16. *When will three neutral beams be operational?*

As discussed in Question #15, above, the three neutral beams will be operated for the first time as complete systems from about December 1983 to June 1984 in order to qualify the operation of the beams and to understand the interaction between the beams and the plasma. At the end of this period, the beams will be fully operational.

17. *Have the upper poloidal field coils been delivered?*

The TFTR inner poloidal field coils have been delivered. The upper and lower outer poloidal field coils are being manufactured by Princeton Plasma Physics Laboratory and are nearing completion in sufficient time to support the assembly of the tokamak which is currently under way. In fact, the first large diameter outer poloidal field coil has already been installed on the tokamak base in the test cell.

18. *What is the present status of the internal support structure (ISS)?*

The TFTR Internal Support Structure (ISS) has been successfully completed. The inner poloidal field coils are now being mated with the ISS, and this full assembly is scheduled for delivery to TFTR in January 1982.

19. *Have the vacuum and controls systems been tested?*

The TFTR vacuum system consists of conventional mechanical equipment, all of which has been tested in accordance with standard prescribed procedures. The full integration and test of this equipment with the TFTR vacuum vessel will be completed in December 1982. With regard to the control system, the computers have been accepted, and the TFTR control system is now operational and is currently being used in the conduct of TFTR equipment tests as the equipment is brought on line. The full capability of this system will be demonstrated in the complete systems test scheduled in December 1982.

20. Has the cryogenic system been tested?

The principal TFTR cryogenic equipment is now under test at Princeton Plasma Physics Laboratory. The final cooldown and test of the equipment at the operating temperature are on schedule to be completed in February 1982.

21. What is the milestone schedule for integration of subsystems and systems in TFTR?

The TFTR milestone schedule for integrating and testing subsystems in support of the first plasma date follows:

System Test	Completion Date
Motor Generator (MG Set #1)	5/82
Cooling Water	6/82
Coil Power Supplies	10/82
Vacuum Vessel	12/82
All Coil Systems	12/82
Diagnostics	12/82
TFTR System (First Plasma)	12/82

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MINORITY STAFF DIRECTOR

February 9, 1982

Dr. Alvin Trivelpiece
Director, Office of Energy Research
Department of Energy
Washington, DC 20585

Dear Dr. Trivelpiece:

The Subcommittee is evaluating the Department's Fiscal Year 1983 budget request for the Magnetic Fusion Energy Program. To facilitate this evaluation, I am enclosing a copy of additional questions the Subcommittee staff has concerning the program. I hope that this additional information can be made available to us by February 22, 1982.

Thank you for your assistance.

Sincerely,

John V. Dugan Jr.
JOHN V. DUGAN, JR.
Staff Director
Subcommittee on Energy Research
and Production

JVD:Wma
Enclosure

February 9, 1982

QUESTIONS TO THE
DEPARTMENT OF ENERGY
MAGNETIC FUSION ENERGY PROGRAM

1. a) What are the detailed FY 1981, FY 1982 and FY 1983 objectives, funding levels, and program milestones for the Toroidal and Mirror Confinement Systems subactivities of the OFE's Confinement Systems activity?

   b) Provide justification of how each of the tasks/subtasks/projects carried out in the Toroidal and Mirror Confinement Systems subactivities support stated objectives.

   c) Provide the detailed operating plans, including FY 1982 and FY 1983 funding levels, for each current or planned facility supported by OFE's Confinement Systems activity, including 1) PLT, 2) PDX, 3) D-III, 4) ISX-B, 5) Alcator, 6) TFTR, 7) D-III Dee, 8) ATF-1, 9) TMX-Upgrade, 10) Phaedrus, 11) STM, 12) MFTF-B, 13) TARA, 14) EBT-S, 15) EBT-P, 16) MMX, and 17) the High Voltage Test Stand Facility.

   d) Provide detailed justification and funding levels for the FY 1983 request of $21.8 million for Confinement Systems capital equipment.

2. a) What are the detailed FY 1981, FY 1982 and FY 1983 objectives, funding levels, and program milestones for the subactivities of the OFE's Development and Technology activity, including 1) Magnetics, 2) Plasma Engineering, 3) Fusion Reactor Materials, 4) Fusion Systems Engineering, 5) Environment and Safety, and 6) Fusion Energy Applications?

   b) Provide justification of how each of the tasks/subtasks/projects carried out in the Development and Technology subactivities support stated objectives.

c) Provide the detailed operating plans, including FY 1982 and FY 1983 funding levels, for each current or planned facility supported by OFE's Development and Technology activity, including as a minimum 1) the Large Coil Test Facility, 2) the High Field Test Facility, 3) the Tritium Systems Test Facility, 4) RTNS-II, 5) the Neutral Beam Engineering Test Facility, and 6) the Gyrotron Test Facility.

d) Provide detailed justification and funding levels for the FY 1983 request of $9.7 million for Development and Technology capital equipment.

3. a) Provide detailed FY 1982 and FY 1983 funding levels for each task/subtask/project carried out by the Applied Plasma Physics activity.

b) Provide detailed FY 1982 and FY 1983 funding levels and justification for each of the small special purpose experiments funded by OFE's Applied Plasma Physics activity, including 1) Versator, 2) Microtor, 3) Macrotor, 4) Tokapole, 5) TERP, 6) TORUS-II, 7) TEXT, 8) PRETEXT, 9) ACT, 10) LAMEX, 11) UC/Irvine Mirror Device, 12) Constance, 13) ZT-40, 14) FRX-C, 15) S-1 Spheromak, 16) Surmac, 17) Octupole, 18) Stellator, 19) TRX-1, and 20) all other appropriate experiments. Identify funding by experimental device and by facility and/or institution.

c) Provide detailed FY 1982 and FY 1983 funding levels for the Fusion Theory subactivity. Identify funding levels of the subactivity for 1) specific portions located at the sites of major programs, and 2) by facility and/or institution.

d) Provide detailed justification and funding levels for the FY 1983 request of $4.0 million for Applied Plasma Physics capital equipment.

4. a) What is the rationale that OFE's GPP request for ORNL includes both the MFE programmatic needs, as well as all of the Laboratory's general needs?

   b) Delineate that portion of ORNL's GPP funding request for FY 1983 which is specific to MFE programmatic needs and that portion which is not.

   c) Provide additional detail and justification for the following GPP funding requests for FY 1983: 1) all LANL projects, 2) Gas and Electric Meters for MFE Facilities at LLNL, 3) Crane for Building Vault at LLNL, 4) New Cryogenics Substation at LLNL, 5) Telephone/Communications at LLNL, 6) Paving, Grading and Landscaping at LLNL, and 7) TFTR Operations Support Office and Laboratory addition.

5. Provide additional details regarding the building site preparation portion of the TARA Tandem Mirror Experiment.

6. The FY 1980 Magnetic Fusion Program Summary Document included Tables II-6, II-7, and II-8, attached for your reference, which provide actual FY 1978 BA, as well as BA estimates for FY 1979-80. Update these tables to include actual BA for FY 1979 and 1980, as well as estimates of BA for FY 1981, 1982 and 1983.

Department of Energy
Washington, D.C. 20585

MAR 22 1982

Mr. John V. Dugan, Jr.
Staff Director
Subcommittee on Energy
  Research and Production
Committee on Science
  and Technology
U.S. House of Representatives
Suite 2321
Rayburn House Office Building
Washington, DC 20515

Dear Jack,

Enclosed is the Office of Fusion Energy's response to the six questions posed in your recent letter, regarding the Subcommittee's evaluation of the Department's FY-1983 budget request for the magnetic fusion energy program.

If this Office can be of any further assistance, please let me know.

Sincerely,

Alvin W. Trivelpiece
Director
Office of Energy Research

Enclosure

Q1.(a) What are the detailed FY 1981, FY 1982 and FY 1983 objectives, funding levels, and program milestones for the Toroidal and Mirror Confinement Systems subactivities of the OFE's Confinement Systems activity?

(b) Provide justification of how each of the tasks/subtasks/projects carried out in the Toroidal and Mirror Confinement Systems subactivities support stated objectives.

(c) Provide the detailed operating plans, including FY 1982 and FY 1983 funding levels, for each current or planned facility supported by OFE's Confinement Systems activity, including 1) PLT, 2) PDX, 3) D-III, 4) ISX-B, 5) Alcator, 6) TFTR, 7) D-III Dec, 8) ATF-1, 9) TMX-Upgrade, 10) Phaedrus, 11) STM, 12) MFTF-B, 13) TARA, 14) EBT-S, 15) EBT-P, 16) MMX, and 17) the High Voltage Test Stand Facility.

(d) Provide detailed justification and funding levels for the FY 1983 request of $21.8 million for Confinement Systems capital equipment.

The Toroidal and Mirror Confinement Systems subactivities are managed as separate programs within OFE. The overall confinement systems budget summary is provided below followed by a detailed response to Question 1, first for Toroidal Confinement Systems, then for Mirror Confinement Systems.

Funding Levels (BA)	FY 1981	FY 1982	FY 1983
Confinement Systems	119,862	156,126	202,800
Toroidal Confinement Systems (TCS)	80,662	102,770	153,300
Mirror Confinement Systems (MCS)	39,200	53,356	49,500

TOROIDAL CONFINEMENT SYSTEMS (TCS)

Q1.(a) What are the detailed FY 1981, FY 1982 and FY 1983 objectives, funding levels, and program milestones for the Toroidal and Mirror Confinement Systems subactivities of the OFE's Confinement Systems activity?

Objectives

TCS:

The major objectives for FY 1982-1983 include:

1. The preparation for and initiation of operations on the Tokamak Fusion Test Reactor (TFTR)

2. Continued investigation of basic physics issues on the existing tokamak facilities including:

    (a) Heating and Current Drive
    (b) Fueling
    (c) Equilibrium and Stability
    (d) Perpendicular Transport
    (e) Impurity Transport
    (f) Self Heating
    (g) Electric Potential

3. Investigation of improvements to Toroidal Confinement Systems including configuration optimization to operate high-beta plasmas under steady-state conditions.

Funding Levels	FY 1981	FY 1982	FY 1983
Toroidal Confinement Systems (TCS)	80,662	102,770	153,300
Research Operations	51,987	50,560	58,550
TFTR	10,625	35,970	69,000
MDF	2,250	3,240	10,150
Capital Equipment	11,300	13,000	15,600
Construction	4,500	--	--

Major Program Milestones

FY 1981

- 6 keV ion temperatures achieved with 6 MW of perpendicular neutral beam injection on PDX.
- The beta achieved on the Impurities Studies Experiment (ISX-B) increased to 2.5% (above the ideal MHD limit).
- Current drive was demonstrated to 1 second pulses at low densities using lower hybrid waves on PLT.

FY 1982

- Increase ion cyclotron heating power to 3-4 MW by the end of FY 1982 which would demonstrate the viability of ion cyclotron heating as a serious contender for heating power reactors.
- Explore long pulse rf current drive at modest power using lower hybrid on PLT.
- Complete fabrication of the OH startup diagnostics and controls for TFTR.
- Begin investigating the physics of electron cyclotron heating in tokamaks (PDX and Doublet III) at the higher densities accessible with the 60 GHz gyrotrons under development in the D&T program.
- Demonstrate multi-pellet plasma fueling on PDX and Alcator C.

FY 1983

- Begin physics operation of TFTR with full ohmic diagnostics set.
- Start up TFTR for initial systems checkout.
- Test beta limits in the range of 5% with an elongated plasma cross-section in Doublet III with 10 MW of installed neutral beam power.
- Extend ICRF heating experiments in PLT to the full 4-5 MW capability of the experiment.

Q1.(b) Provide justification of how each of the tasks/substasks/projects carried out in the Toroidal and Mirror Confinement Systems subactivities support stated objectives.

The chart below shows in matrix form how each of the budget tasks supports the TCS program objectives as stated in the reply to Question 1.a.).

Toroidal Progran. Matrix

			PLT	PDX	D-III	ISX-B	ALC. C	TFTR	D-III DEE	ATF
Status			Operating	Operating	Operating	Operating	Operating	Under Construction	Planned	Planned
Unique Capability			ICRF, Current Drive	Impurity Control	Low q Shaped Plasmas	High β	High Field High Density	Break even DT Plasmas	FED Plasma Engineering	Toroidal Optimization
Physics Issue	Tokamak FED Issue	Advanced Toroidal Issue								
Heating & Current Drive	ICRF Non OH Start Up		3.0 MW ICRF, LH Current Drive						FED Prototype	
		Steady State Bulk Heating Method		ECH (Physics)	ECH (High Power)		LH Current Drive at High N			Steady State Demonstration
Fueling	Pellet Fueling			Four Pellet Injector		High Velocity Injector				
		Same as for FED								
Equilibrium & Stability	β = 5% Disruption Control				Low q Shape Optimization	2.5% β, Circular Shape			FED Prototype	
		Higher β Values								High β, Disruption Free
Perpendicular Transport	Minimum Size for Q = 5		Transport at High Temp				Transport at High Density	Major Size, Temp Scaling		
		Minimum Size for Ignition								Improved Confinement
Impurity Influx	Mechanism Vs Magnetic Divertor			Optimized Magnetic Divertor	Expanded Boundary				FED Prototype	
		Optimized Control Method								Optimized Impurity Control Method
Self Heating	α Particle Heating		Simulation With Beams					Study α Particle Deposition		
		Same as for FED								
Electric Potential	Thought to Have Some Effect on Transport					Exp. to Meas. El Pot. Planned				
		Same as for FED								

Q1.(c) Provide the detailed operating plans, including FY 1982 and FY 1983 funding levels, for each current or planned facility supported by OFE's Confinement Systems activity, including 1) PLT, 2) PDX, 3) D-III, 4) ISX-B, 5) Alcator, 6) TFTR, 7) D-III Dee, 8) ATF-1, 9) TMX-Upgrade, 10) Phaedrus, 11) STM, 12) MFTF-B, 13) TARA, 14) EBT-S, 15) EBT-P, 16) MMX, and 17) the High Voltage Test Stand Facility.

Detailed operating plans for the major TCS facilities are as follows:

1) PLT/PDX

		FY 1982	FY 1983
Budget Request:	Operating	14,750	18,000
	RF (CMFE Support)	2,000	

The PLT and PDX share power supplies and support resources. They are being treated as a common budget element.

PLT

The PLT program has been at the forefront of worldwide tokamak research since its beginning of operations in 1976. It still holds the record for highest ion temperatures (∿ 7.2 keV) in the neutral beam heating of tokamaks, and longest confinement time (100 msec) in ohmic heated discharges.

The emphasis during the past two years has been development of radio frequency (rf) heating techniques. PLT is also at the forefront of this worldwide endeavor. Significant electron and ion heating has been achieved with different modes of ICRF heating (second harmonic and minority heating). The possibility of steady-state current drive by rf was demonstrated in FY 1981 on PLT when about 250 kA of plasma current was sustained for a 1 sec long pulse with lower hybrid waves in the absence of ohmic heating power. This pulse length was limited to one second only by the existing rf hardware. A current of 500 kA was sustained for shorter pulses.

In addition to these neutral beam, rf heating, and steady-state current drive results, the experiments on PLT have contributed to the investigations of confinement scaling, ripple, impurity transport, plasma rotation, plasma-wall interactions, and low q discharges.

With increased attention to the high-beta issues in the toroidal program, PLT recently ran in a high-beta configuration with neutral beam heating. About 2% beta was achieved with 1.8 MW of neutral beam power.

The plan in the remainder of FY 1982 is to continue ICRF and lower hybrid programs and to pursue high-beta studies with both ICRF neutral beam heating independently, and also with the combination of neutral beam and ICRF heating.

There is available about 2 MW of 25 MHz or alternatively 5 MW of 42 MHz ICRF power on the device. The power delivered to the plasma, however, is limited by the antenna feedthroughs and the antennas themselves. During the past year the feedthrough design and antenna conditioning were improved, and the level of ICRF power delivered to the antenna is being raised gradually. It stands at 2.2 MW at the present. This level should be at about 3 MW by the end of FY 1982, which will make it possible to have a good assessment of ICRF heating of large tokamaks.

The high-beta configurations will be investigated in such ICRF heated hot plasmas, and also in neutral beam and ICRF heated plasmas which should provide about 4 MW of heating power. Also, the effects of plasma rotation will be investigated on PLT which has both co- and counter-injection beams.

The LH current drive hardware will be improved in FY 1982 in order to extend the pulse length of steady-state current drive experiments to about 10 sec. The LH system is also being used to investigate bulk plasma heating.

In FY 1983 the ICRF heating power will be raised to its maximum of about 5 MW by improved antenna design; improved waveguide launchers for the ICRF will also be explored, and the long pulse LH current drive experiments will be continued. Also, the LH system will be improved to raise its frequency in order to investigate current dirve at higher plasma densities.

The investigations of impurity transport, plasma-wall interactions (edge physics), and confinement scaling will continue in FY 1982 and FY 1983.

PDX

The Poloidal Divertor Experiment (PDX) is a large, versatile tokamak incorporating four sets of poloidal divertor coils inside its vacuum vessel. These coils are capable of producing several macroscopically stable poloidal divertor configurations including a square cross-section, a dee-shaped plasma, and an inverse dee-shaped plasma. In addition, PDX has a 6-8 MW neutral beam heating system consisting of four injectors aimed near perpendicular to the minor axis.

The primary role of PDX within the TCS program is to determine the neutral beam heating efficiency as a function of basic plasma parameters, to find conditions under which beta saturates with heating power, and to examine this limit as a function of plasma shape. A secondary, but important, part of the program is to study the physics of divertor plasmas and to improve the energy and particle handling aspects of divertors. The ultimate goal is a computational divertor model of sufficient reliability to serve as a design tool for the next generation of tokamaks. Additional objectives include investigating the physics of electron cyclotron heating and studying the viability of fueling the plasma by pellet injection.

During FY 1981 PDX (with an effective plasma volume of $5m^3$) reached ion temperatures of 6 keV in plasma densities of $4 \times 10^{13}cm^{-3}$ using 5.5 MW of injected neutral beam power. This represents a new high for the energy contained within a fusion plasma device.

For FY 1982, attempts will be made to optimize the neutral beam injection results using improvements to the pumping and divertor systems for impurity control. The magnetic field will be lowered to probe the beta limits that can be reached in PDX, both with and without the divertor (the non-divertor plasmas are more or less circular). A new pumped limiter will be added to examine this mode of helium ash removal for FED and future machines. A multi-pellet particle fueling experiment will be tested as a means of altering the density profile in PDX and future devices. A physics investigation of ECH heating in tokamaks will begin using the new pulsed 60 GHz gyrotrons which raise the accessible density regions for ECH to the more relevant 4-8 x $10^{13}cm^{-3}$ as opposed to previous tubes which were limited to 1/4 those values.

For FY 1983, emphasis at Princeton will shift heavily toward the startup of TFTR. Experimental operations on PDX, which shares power supplies with PLT, will depend upon the relative importance which is placed on the high power neutral beam, beta, and impurity experiments on PDX as opposed to the rf heating and beta experiments which can be performed on PLT.

2) D-III

	FY 1982	FY 1983
Funding Levels:	14,830	16,000

The Doublet III device is used to study confinement and transport properties of plasma with noncircular cross-sections. The objective of these experiments is to obtain the efficient use of magnetic fields (high beta). In addition, a variety of advanced tokamak/FED experiments such as impurity control methods using expanded boundaries are being pursued.

The field shaping is accomplished with a set of coils mounted around the periphery of the doublet-shaped plasma chamber. Although the plasma temperature resulting from ohmic heating is high, supplemental neutral beam injection will produce a higher plasma temperature similar to reactor conditions. The bottom half of the chamber is useful for performing impurity control experiments, using magnetic divertors when singlet plasmas are produced in the top half.

An agreement was reached in FY 1979 on a 5-year Doublet III cooperative program, in which the Japan Atomic Energy Research Institute (JAERI) would provide funds (approximately $70 million) for upgrading the Doublet III facility for operation with increased magnetic field, plasma current, neutral beam power and, possibly, a dee-shaped vacuum chamber in exchange for equal operating time on Doublet III; the JAERI funds also pay the incremental cost of operating a second shift on D-III. In early FY 1980, the first upgrade steering committee meeting was held. This committee provides overall direction to the D-III upgrade program. JAERI sent a team of scientists to conduct experiments beginning in September 1979.

During FY 1981, simplified, reactor-relevant impurity control and plasma confinement were studied. Near reactor-grade plasma experiments, using up to 7.2 MW of neutral beam injection power, will commence near the end of FY 1982. This power may be sufficient to test the beta limits of circular configurations.

During FY 1982 the neutral beam power from the first two neutral beam lines is being increased with a goal of having 5.0 MW by the summer of 1982. Presently up to 2.0 MW has been injected into D-III plasmas. The object of the experiments is to achieve high-beta values. A total of 2.0 MW has been injected into low q plasmas yielding beta values of 2.2%. The first test of ECH heating at 60 GHz in D-III using pulsed tubes will also be initiated in FY 1982.

The present phase of the experiment is expected to become power limited in late 1982, and therefore a shutdown for installation of a third neutral beam line is scheduled for late CY 1982 (early FY 1983). The shutdown is expected to take about four to five months. When operations resume, the total heating capability will be 10 MW which is expected will produce a demonstration of the beta values of 5% which are required for FED. A full 1 MW of 60 GHz ECH power with essentially cw capability will also be installed in FY 1983.

Near the end of FY 1982 operations with both neutral beam lines at full power will be under way. Beam operations will require greater operating staff in FY 1983.

In addition, about ten new diagnostics including a multi-point Thomson scattering system and neutral particle analyzer will have been added to Doublet III by the end of FY 1982. Although some earlier diagnostics have been automated, the net result will be a need for increased manpower.

Because of the increased number of heating systems and diagnostics, it will be possible to obtain information about FED prototype hydrogen plasmas with a greater understanding. About five additional physicists will be required to analyze the data.

The situation for FY 1983 at the given funding level can be summarized as follows: the top priority program which is to demonstrate high-beta values in dee-shaped FED relevant plasmas will be pursued. The remainder of the basic program will proceed somewhat slower than optimum because of lack of spares and constrained operating funds.

Actual implementation of the long pulse ECH heating power may be deferred into FY 1984.

3) ISX-B

	FY 1982	FY 1983
Funding Levels: Operating	9,800	10,700

The ISX-B facility at ORNL is one of the principal elements of the U.S. tokamak program. The experiments on this facility have provided significant information to the advancement of the national tokamak effort, the design and evolution of the FED concept, and the improvement of the tokamak reactor concept. Areas of investigations have included high-beta tokamak configurations, electron cyclotron heating, ripple effects and ripple injection, pellet fueling, impurity generation and support, plasma-wall interactions, and particle control by pumped limiters and bundle divertors. Experiments in all of these areas will continue in FY 1982 and FY 1983 with minor improvements to the facility which will include increasing ohmic heating current capability, installing a third beam line, and upgrading diagnostic capabilities.

The major emphasis in FY 1982 will be to explore further the physics of high-beta configurations. Empirical data from ISX-B indicate that toroidal or poloidal beta increases less than linearly with neutral beam power at high injection powers. It has been postulated that this observation may be a result of plasma rotation induced by having only co-injection beam heating. The plan is, therefore, to install a surplus PLT beam line in the counter-injection position in June 1982 in order to heat the plasma with balanced co + counter beam injection (no plasma rotation). The effect of plasma rotation on beta will thus be apparent in these experiments.

A second empirical observation on ISX-B is that confinement, hence beta, improves with increasing current in neutral beam heated discharges. The ohmic heating power supply is, therefore, being upgraded and the toroidal field coils are being strengthened in order to increase the ohmic current to about 300 kA from its present limit of 220 kA. This higher current capability will also be available in June 1982.

New diagnostics have been added to the device recently which will improve data acquisition and will provide for a better understanding of the physics of high-beta configurations. Some of these are multi-channel Thomson scattering system (SCATPAK II) to measure density and temperature profiles, and Infrared Interferometer/Faraday Rotation System to measure current profiles and high-frequency fluctuations.

In addition to the high-beta studies, the experiments on ripple effects, impurity generation and transport, and plasma-wall interactions will continue in FY 1982.

The high-beta studies will be continued in FY 1983. A collaborative program with Renssalaer Polytechnic Institute will provide for measurements of plasma potential which will contribute to the understanding of confinement and beta issues.

Other areas that will receive an increased effort in FY 1983 include investigations of steady-state current drive, bulk heating and profile control by ECRH techniques, the evaluation of pumped limiters, and the improvement of plasma fueling by solid hydrogen pellet injectors. The ECRH program will be carried out in collaboration with team from NRL which has developed a 35 GHz, 300 kW gyrotron with 30-40 msec pulse length.

It is thus anticipated that there will be significant contributions from the ISX-B program in FY 1982 and FY 1983 leading to an understanding of the physics of high-beta configurations with a wide range of measurement and systematic experiments. In addition, the ISX-B program will contribute to the FED concept and the advancement of toroidal concepts with results from pumped limiters, the plasma-wall interaction program, ECRH current drive, pellet fueling, and ripple studies. The front end of the ISX-B facility is then expected to be replaced with that of the Advanced Toroidal Facility (ATF-I) in FY 1986. The principles of steady-state operation of high-beta configurations will be investigated on ATF-I.

4) Alcator C

	FY 1982	FY 1983
Funding Levels: Operating	8,010	8,500

The primary goal of the Alcator C program is to produce plasmas with confinement times and densities necessary for breakeven. A second major goal of the Alcator program is to study lower hybrid (LH) heating and current drive in high density plasmas. Alcator will also be used to study pellet fueling in a high density tokamak.

The Alcator C tokamak is capable of operating over an extremely broad range of parameters--B_T = 4-12T, n_e = 0.3-8 x 10^{14}cm^{-3}, and plasma currents up to 750 kA. Thus, Alcator C may be used to investigate the characteristics of tokamak plasmas in any reactor relevant range. In addition, at high fields and currents, the ohmic power density in Alcator C is ≥ 10 W/cm^{-3}, which is equal to the power density achieved in other experiments with auxiliary heating.

During the first half of FY 1982, the dominant activity on Alcator C will be a continuation of the confinement research. During the second half of FY 1982 lower hybrid heating and current drive experiments will become an increasingly important part of the Alcator program.

The Alcator C tokamak is potentially capable of nτ values of 8-10 x 10^{13}; however, the highest values obtained to date are in the 3-4 x 10^{13} range. In an attempt to increase the nτ in Alcator, MIT is installing an additional 50 MW ohmic heating power supply. This will permit higher currents in Alcator (up to 1 MA); there is empirical evidence that this should lead to improved confinement results. In addition, MIT is cooperating with ORNL on pellet fueling experiments, which may alter the density profiles and thereby improve the confinement.

Low power lower hybrid heating experiments at powers up to 160 kW have recently been completed, and the coupling of the rf power to the plasma is good. In March, a 4 x 4 waveguide array will be installed, and high power experiments at the 500-1,000 kW level can begin. In addition, a series of high power lower hybrid current drive experiments will also be carried out on Alcator C. In previous low power current drive experiments, it has been possible to drive currents at plasma densities of > 10[illegible] cm^{-3}, a higher density than in other tokamaks.

In FY 1983 the dominant activity on the Alcator C tokamak will be the high power lower hybrid heating and current drive experiments. Additional 4 x 4 waveguide arrays will be installed to permit 3-4 MW of rf power to be delivered to the plasma. This amount of rf power should raise the ion and electron temperatures to the 3-4 keV range.

Confinement experiments will also continue in FY 1983. MIT will operate Alcator C at the full design toroidal field of 12-14T and full design current of 1 MA.

5) TFTR

	FY 1982	FY 1983
Funding Levels: Total	35,970	69,000
Experimental Operations	3,000	13,200
Diagnostics	8,200	13,000
CICADA	4,200	7,000
Facility Operations	20,570	23,300
Technical Support	--	12,500

The objectives of the Tokamak Fusion Test Reactor (TFTR) are the demonstration of plasma energy breakeven (Q ∿ 1), the testing of reactor relevant concepts, and ultimately the investigation of the physics of thermonuclear plasmas in conditions approaching Q ∿ 2.

During FY 1982, TFTR will be completing final preparations for operations and in FY 1983 will begin the transition to experimental operations with a resulting shift in the funding from construction to operations (with essentially no change to the overall TFTR budget).

The initial plasma operation (December 1982) will be designed to check out major systems in an integrated fashion. Full scale experimental operations with an ohmic plasma will begin in April-June 1983.

The separate TFTR budget elements are described below:

Experimental Operations is responsible for the formulation and execution of an experimental schedule, the development and use of codes to model and analyze plasma behavior, the design and operation of hardware for physics-oriented systems (such as glow discharge cleaning, limiters, position and density feedback controls, and pellet injectors), and finally the actual physics operation of TFTR itself.

Diagnostics is responsible for carrying research and development for new diagnostics necessitated by TFTR's size, temperature, or neutron emissions and for building advanced diagnostics which are scaled up from PDX/PLT diagnostics. A minimum set of diagnostics will be completed in FY 1982 to be available for the initial machine checkout (voltage loops, average density, radiometer temperature). A more complete basic set of plasma diagnostics with some profile information is being prepared for the OH startup in April-June 1983. Work on complete profile diagnostics from multiple views and D-T diagnostics has been deferred in many cases because of funding limitations.

The CICADA effort provides the computer system, user operating station, hardwired interlocks, and the timing and communication systems for the TFTR facility. Most of the CICADA computer system is installed and operational, and much of the effort remaining concerns the acquisition and installation of peripherals and the development and testing of the software which will permit collecting and archiving up to 40 million bytes of data from a TFTR shot. Several diagnostic systems are being used to prototype operations with CICADA. By FY 1983, CICADA will be heavily involved in supporting TFTR operations. There will continue to be additional development efforts associated with improved techniques for controlling the energy conversion system, plasma feedback, etc., as well as establishing an interface to the Laboratory computer system.

Facility operations is responsible for operating and maintaining all of the components, equipment, and subsystems that comprise the tokamak device, its auxiliary systems, and the building and supporting plant facilities.

At the end of FY 1982 and throughout FY 1983, TFTR Facility Operations will be supporting a dual testing and research effort. After achieving an initial hydrogen plasma, major blocks of operating time will be devoted to checking out operating scenarios and diagnostic equipment and to conducting plasma handling studies of ohmic-heated plasmas in hydrogen and deuterium. Operating periods for debugging and preoperational testing will be interspersed with these physics-research-related runs, in order to complete work on the several tokamak systems which will not have been fully qualified at the time of the first hydrogen plasma, and also to install, test, debug, and bring into full operation the three neutral beamline heating systems that are included in the baseline project. To meet the required objectives during the first year of operation, it is expected that the running time will be roughly equally split between the installation/debugging/preoperational testing work and the experimental physics research program.

Technical Support is a new category breakdown to cover the ongoing engineering effort to modify, improve, or repair device components. This budget area will undertake and continue major engineering preparations for specific tritium handling, remote handling, and shielding usage required for the earliest possible D-T experiments.

6) D-III DEE

	FY 1982	FY 1983
Funding Levels: Operating	$.5M*	$5.0M

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*CMFE Support

During FY 1982 and FY 1983, Doublet III will be completing its neutral beam heating, high-beta experimental work in the upper lobe of the present doublet-shaped vacuum vessel. The doublet plasma configuration has proved to be operationally difficult to work with and we now believe that a dee-shaped plasma configuration is adequate for FED and for a tokamak reactor. The Doublet III Dee project will replace the present doublet-shaped vacuum vessel with a large dee-shaped vessel. This modification is a cost-effective means of obtaining a large dee-shaped facility on which prototypic tokamak reactor element can be mocked-up and tested in a hydrogen plasma. It will extend and maximize the usefulness of the present facility through 1990.

The base cost estimate for converting the Doublet III facility to a large Dee is $13M. During FY 1982, $.5M will be spent on physics and conceptual design work. During FY 1983, the final design will be completed and the vacuum vessel and ancillary hardware will be fabricated.

It is anticipated that the Japanese Atomic Energy Research Institute (JAERI) will extend the present cooperative program on Doublet III and will contribute approximately $9M to enhance the Doublet III Dee project. If this occurs, the power systems and ancillary vessel hardware will be increased to allow a closer simulation in a hydrogen plasma of conditions in a tokamak reactor.

7) ATF-1

	FY 1982	FY 1983
Funding Levels:	0*	3,000

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*This project is an evolution of the ISX-C project and design will proceed under unexpended funding authorized for that project.

The presently operating ISX-B tokamak will be modified to test advanced toroidal fusion confinement concepts, which would provide significant advantages for proposed tokamak fusion reactors. The modified device, ATF-1, is intended to test beta limits and collisionless transport in current-free stellarator/torsatron configurations with later extension to hybrid (stellarator/tokamak) devices.

Present stellarator experiments are small with relatively poor confinement parameters. Nevertheless, experiments in West Germany and Japan have increased confidence in the confinement capability of this concept, which is similar to the tokamak but which has no internal plasma current and is, in principle, a steady-state concept. ATF-1 is intended to test stellarator confinement and beta limits at a level comparable with that of present day mainline tokamaks like ISX-B or PLT. In addition, ATF-1 will provide an experimental basis for beginning stellarator/tokamak hybrid studies with the intention to explore possible optimized confinement configurations with the advantages of both stellarators and tokamaks.

The basic ATF-1 device consists of a stellarator coil set, a vertical field winding, an ohmic heating system, and a vacuum vessel. Magnetic configuration flexibility, a large cross-section, and good access are important design considerations. It will utilize all of the existing ISX-B facilities, including power supplies, instrumentation and control systems, utilities, diagnostics, etc.

The fabrication of the components will be carried out in FY 1984-FY 1985, while the ISX-B device continues experimental operation, and the installation of the components will be accomplished in FY 1986.

In FY 1982, conceptual design and long-lead procurement will begin. These activities will be completed in FY 1983 and final design will be underway.

Q1.(d) Provide detailed justification and funding levels for the FY 1983 request of $21.8 million for Confinement Systems capital equipment.

Capital Equipment Funds	FY 1983
Confinement Systems (BA)	$21,800K
Toroidal Confinement Systems (TCS)	$15,600K
PPPL - TFTR	$ 8,000K
PPPL - PLT/PDX	2,000K
MIT	1,200K
ORNL	2,000K
GA	2,400K

Capital Equipment funds are used both in the continuing upgrade and improvement of the diagnostics, power supplies, and miscellaneous peripherals of existing facilities and also in the buildup of new facilities such as TFTR. Of the $15,600K of Capital Equipment funds requested for TCS for FY 1983, $8,000K is required for TFTR and $7,600K is required for ongoing experiments. A more detailed description of these requirements by laboratory follows:

PPPL - TFTR

A total of $8,000K of capital equipment funds is required by TFTR including $2,400K for an off-line analysis computer, an experimental computer, and a mass data storage unit; $740K for X-Ray diagnostics; $140K for neutron diagnostics; $460K for surface analysis systems; $250K for cyclotron emission diagnostics; $140K for interferometer systems; $300K for laser systems; $410K for charge exchange ion temperature diagnostics; $900K for a diagnostic neutral beam power supply; $800K for supporting services equipment; and $1,460K for miscellaneous other diagnostics and vacuum equipment.

PPPL - PDX/PLT

A total of $2,000K is required for PDX/PLT, principally in support of ongoing experiments, but including $400K for an 80 MHz RF amplifier.

Also included is $80K for rf test equipment, $210K for data acquisition equipment, $120K for dual programmable amplifiers, and $1,190K for miscellaneous diagnostics and support service equipment.

MIT

A total of $1,200K is required for Alcator C. This machine is a relatively mature experimental device; most of the capital equipment is for auxiliary systems and diagnostics such as $215K for CAMAC crates and other data acquisition peripherals, $215K for a multipulse Thomson scattering laser, $200K for new spectrometers, and $570K for miscellaneous vacuum, cryogenic and control systems.

ORNL

A total of $2,000K is required for ISX-B including $300K for diagnostics modifications, $740K for data acquisition improvements, $150K for a poloidal field supply upgrade and $810K for miscellaneous diagnostic, vacuum and control systems.

GA

A total of $2,400K is required for Doublet III including: power systems instrumentation test equipment/meters, scopes computer interfaces/memory peripheral equipment ($345K); computer, memory, etc., scopes, terminals and other peripherals ($455K); operations support and test equipment, diagnostics, equipment and upgrades, reliability modification ($588K); ion source rebuild equipment, power systems instrument test equipment, computer interfaces/memory peripheral equipment ($645K); optical multichannel analyses, system interlocks, armor monitor equipment ($260K); and miscellaneous instrumentation ($107K).

End of TCS answers.

MIRROR CONFINEMENT SYSTEMS (MCS)

The Mirror Confinement Systems (MCS) subactivity supports activities in the tandem mirror (open systems) and elmo bumpy torus (closed system) areas. MCS also provides programmatic guidance and overview for the Mirror Fusion Test Facility-B (MFTF-B) construction project, which is funded through the Division of Planning and Projects. The goal of the MCS program is to develop superior reactor confinement configurations, and to guide these concepts to the stage of convincing technological demonstrations. MCS programs are oriented toward that end.

Funding Levels	FY 1981	FY 1982	FY 1983
Mirror Confinement Systems (MCS)	39,200	53,356	49,500
Research Operations	17,150	30,387	36,700
Major Device Fabrication (MDF)	10,250	4,313	6,600
Capital Equipment	6,400	5,210	6,200
Construction	5,400	13,446	0

The MCS answers to question 1 are given first for the tandem mirror subprogram, then for the elmo bumpy torus subprogram, then for MFTF-B.

Tandem Mirror Program

Q1.(a) What are the detailed FY 1981, FY 1982 and FY 1983 objectives, funding levels, and program milestones for the Toroidal and Mirror Confinement Systems subactivities of the OFE's Confinement Systems activity?

Objectives

MCS Tandem Mirror Program

The major tandem mirror objectives for FY 1982-1983 include:

1. The preparation for and initiation of operations on the Tandem Mirror Experiment-Upgrade (TMX-U).
2. Continued investigation of critical basic physics issues on existing tandem mirror facilities including:
   - (a) Heating
   - (b) Fueling
   - (c) Equilibrium and Stability
   - (d) Perpendicular Transport
   - (e) Impurity Control
   - (f) Electric Potential
   - (g) Parallel Transport
3. Continued fabrication of a versatile axisymmetric research tandem mirror (TARA).

Tandem Mirror Program Funding Levels

Funding Level	FY 1981	FY 1982	FY 1983
Total	22,726	25,945	33,580
Research Operations	7,951	18,287	22,700
MDF	10,250	4,313	6,600
Capital Equipment	4,525	3,345	4,280

Major Tandem Mirror Milestones

FY 1981

- Detailed analysis of the results of tandem mirror operation on TMX gave definitive positive conclusions of the viability of the tandem mirror concept as an attractive reactor configuration.
- TMX-Upgrade major device fabrication was initiated and nearly completed, essentially on schedule.
- First successful operation of a tandem mirror without neutral beams was achieved on Phaedrus, where the plasma was sustained entirely by RF power.

FY 1982

- Complete fabrication of and begin debug operation of TMX-U. This milestone was achieved in early December 1981.
- Begin physics experiments in TMX-U and test reduced microstability due to sloshing ions and proceed to heat end plug plasma with ECH.
- Begin TARA fabrication to include building site preparation and procurement contracts for magnets and vacuum tanks.
- Test startup of tandem mirrors with reduced streaming gun plasma on Phaedrus.

FY 1983

- Demonstrate existence of thermal barrier and improved center cell confinement due to barrier on TMX-U.
- Continue fabrication of TARA to include completion of building site preparation and installation of magnet power supplies and fabrication of magnet coils and vacuum tanks.
- Investigate on Phaedrus the stability boundaries of both microinstabilities and MHD instability in an RF sustained, neutral beam fueled tandem mirror.

Q1.(b) Provide justification of how each of the tasks/subtasks/projects carried out in the Toroidal and Mirror Confinement Systems subactivities support stated objectives.

The following chart shows in matrix form how each of the budget tasks support the MCS program objectives as stated in the reply of Question 1.(a).

Mirror Program Matrix

		TMX-U	Phaedrus	STM	MFTF-B	TARA	EBT-S	EBT-P
Status		Checkout	Operating	Operating	Under Construction	Construction About to Start	Operating	In Design
Unique Capability		Thermal Barriers	R.F. Tests	Hot Electron Stabilization	Breakeven Conditions	Axisymmetry	Only Bumpy Torus in U.S.	Proof of Principal Test
Physics Issue	Concept Improvement Issue							
Heating	Steady State R.F. & Beams		ICRH Research	ECRH Research	High Power Heating	Neutral Beam Design	Steady State ECRH/ICRH	High Frequency S.S. ECRH ICRH
Fueling	Pellet Injection/ Radial Diffusion or Axial Trapping		Axial R.F. Trapping		Radial & Axial Fueling Tests			Pellets Radial Injection
Equil. Stability	Axisymmetry Beta Limits Loss Cone Mode	Microstable End Cells		MHD Stability by Rings		Average Minimum B		Test Beta Limits
Perpendicular Transport		First Measurements			Major Scaling Experiment	Test Axisymmetry Effect	A.R.E. Coils	Major Test
Impurity Control	Not a Problem So Far	Test "Self Divertor" Action						Major Test
Self Heating	Alpha Particles				Particle Simulations Planned			
Electric Potential	Tandem Mirrors Axial E EBT-Radial E	Thermal Barrier Test	Axial Measurement		Radial/Axial Profile Studies		Radial Profiles	Detailed Studies Planned
Parallel Transport	End Loss From Open Systems	End Loss Reduction by Thermal Barriers			Major Scaling Experiment			

Q1.(c) Provide the detailed operating plans, including FY 1982 and FY 1983 funding levels, for each current or planned facility supported by OFE's Confinement Systems activity, including 1) PLT, 2) PDX, 3) D-III, 4) ISX-B, 5) Alcator, 6) TFTR, 7) D-III Dee, 8) ATF-1, 9) TMX-Upgrade, 10) Phaedrus, 11) STM, 12) MFTF-B, 13) TARA, 14) EBT-S, 15) EBT-P, 16) MMX, and 17) the High Voltage Test Stand Facility.

Detailed operating plans for the major MCS tandem mirror facilities are as follows:

1) TMX/TMX-U

	FY 1982	FY 1983
Funding Levels: Total	16,880	21,900
Research Operations	13,737*	18,900+
MDF	913	0
Capital Equipment	2,230	3,000

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*An additional $1,750 of LLNL GSO is being used.
+FY 1983 is the first full year of operation of TMX-U.

TMX

TMX was the first device in the world to test the principles of the tandem mirror confinement for Q-enhancement. The experiment was basically designed with information acquired from the 2X-IIB mirror experiment. Each TMX end plug is similar in size to 2X-IIB. TMX served as a proof-of-principle experiment for the tandem mirror concept and provided the basis for consideration of the conversion of MFTF to the tandem mirror configuration as MFTF-B. TMX operation was discontinued in November 1981 to allow for an upgrade to TMX-U.

TMX-U

As upgraded, the TMX-U experiment will provide scaling data, examine relevant physics issues, and test new ideas, such as the thermal barrier, to improve the tandem mirror performance by reducing energy losses out the ends of the device. The TMX-U is now being put into operation, and is the only operational thermal barrier tandem mirror in the world. The Japanese are building Gamma 10, which is approximately the same size as TMX-U, and will be operated in FY 1983.

TMX-U differs from TMX primarily in the end plug. The axial density and potential profiles required of the thermal barrier plasma are produced by selective heating of electrons by ECRH, and by means of neutral beams injected at an angle to produce specific ion distributions. In addition, TMX-U will achieve center cell electron temperatures of approximately 1 keV. The end plugs of TMX-U will operate at non-equilibrium equivalent ion temperatures in access of 10 keV. The results from TMX-U experiments are expected to be used in refining MFTF-B experimental program plans.

The TMX-U operating plan is described in the Livermore document UCID-19065, titled "TMX-U Initial Operating Plan". The operating plan was jointly developed by LLNL and DOE. During early CY 1982, TMX-U is being checked out. In March 1982, first plasma experiments are scheduled to begin. Research on the end plug "sloshing ion distribution" will be completed by May 1982. Sloshing ions are important in that they help to control microinstabilities in tandem mirrors. The electron cyclotron resonant heating (ECRH) experiments will be started during the early summer of 1982. ECRH is used to establish the correct type of thermal barriers. Experiments to test the creation of the thermal barriers will be carried out in the October to December 1982 timeframe. If successful, the thermal barrier tandem mirror appears to be an excellent reactor candidate. During the spring of 1983, measurements will be made on TMX-U related to power balance, that is, axial and radial energy losses. In the summer of 1983, experiments will be done to change the positive electrostatic potential of TMX-U to an overall negative potential. This can further simplify the reactor design. By January 1984, more neutral beam power will be added to the TMX-U center cell to improve performance, and experiments will be done related to using tandem mirrors as a neutron source.

TARA

	FY 1982	FY 1983
Funding Levels: Total	4,855	8,500
Research Operations	600	900
MDF	3,400	6,600
Capital Equipment	855	1,000

TARA is presently being fabricated. When completed in FY 1984, TARA will provide a highly versatile second major tandem mirror facility which can be used to investigate different magnetic field shapes in tandem mirrors including an axisymmetric design which would encompass EBT type magnetic anchors to stabilize MHD modes and to reduce radial, or perpendicular transport. This plan illustrates the close coupling which exists between the advanced tandem mirror and elmo bumpy torus programs. It initially will not include thermal barriers or have as high a temperature as TMX-U. Tandem mirror reactor designs based on the TARA approach appear to offer economic and engineering advantages over other tandem mirror designs. TARA will allow us to determine if this is true.

Fabrication of TARA will be completed in late FY 1984, and a detailed operating plan has not yet been formulated. The present research operation funds are used to provide technical support for the TARA MDF, to devise the experimental plan, and to conduct small scale research and development tasks related to TARA, such as new methods of pumping down the neutral beam lines by means of ionized gas shutters.

Phaedrus

	FY 1982	FY 1983
Funding Levels: Total	1,170	1,400
Operating Research	1,000	1,200
Capital Equipment	170	200

Phaedrus is a relatively small, university-scale tandem mirror research program. dedicated to exploring RF techniques. It has already been used to establish tandem mirror operation without neutral beam using only RF driven plasmas, and to investigate ballooning mode instabilities using ICRF as a driver in the center cell. As a result of Phaedrus research, ICRF will be added to TMX-U for startup of thermal barrier operation. The Phaedrus work is being carried out by a small professional staff as well as by graduate students. Research is methodically carried out as graduate thesis topics and the program serves to provide qualified scientists for the mirror program. At the present time, Phaedrus research is investigating and comparing startup of a tandem mirror using neutral beams and RF. Later in FY 1982 (June), a systematic effort will be made to investigate micro- and MHD-stability under Phaedrus operating conditions using both RF and neutral beams. In FY 1983, tandem mirror scaling laws will be studied under the same conditions.

MMX

	FY 1982	FY 1983
Funding Levels: Total	350	480
Operating Research	300	400
Capital Equipment	50	80

The Multiple Mirror Experiment (MMX) at the University of California at Berkeley is a small mirror program whose purpose is to test various mirror physics concepts and to train graduate students. Even smaller than Phaedrus, MMX is operated primarily by graduate students under the supervision of two senior faculty members and by a few technicians. The research done at this facility is supportive of the rest of the mirror program and is often used to check tandem mirror theory or to examine a new application. One research project just being completed is on tandem mirror MHD ballooning mode stability boundaries. The next area of research planned is the use of ECRH under tandem mirror conditions. In the fall of 1982, research will be started on hot electron physics.

High Voltage Test Stand (HVTS)

	FY 1982	FY 1983
Funding Level	1,500	700

The HVTS was developed by the D&T program to test neutral beam sources for projects. At the present time the HVTS is being upgraded to test 30 second, 80 kV MFTF-B sources and 80 kV sources for the Doublet III tokamak. The plan is to install the first Aydin neutral beam power supply built for MFTF-B. Aydin has had problems with the control circuits but has now renegotiated their contract so that LLNL will debug the control system. This has resulted in a few months delay, but LLNL feels confident that the new power supply will be installed and usable by the end of FY 1982. Tests on neutral beam sources will begin in the fall. The test stand will eventually be used to test and condition production sources for operating experiments.

Q1.(d) Provide detailed justification and funding levels for the FY 1983 request of $21.8 million for Confinement Systems capital equipment.

Capital Equipment Funds (B/A)	FY 1983
Confinement Systems	21,800
Mirror Confinement Systems (MCS)	6,200
Tandem Mirror Program	4,280
LLNL (TMX/TMX-U)	3,000
MIT (TARA)	1,000
U. of Wisconsin (Phaedrus)	200
UC-B (MMX)	80

LLNL - $3,000,000 (TMX/TMX-U)

Of the requested amount, $1,600,000 is needed for diagnostics for the FY 1983 and FY 1984 program. The diagnostics include items such as ultraviolet spectrographs to measure the electron temperature as a function of position; heavy ion beam probe to measure plasma potential; and a pitch angle end loss analyzer to measure the potential of the barrier.

An amount of $700,000 is requested for equipment for RF experiments, and includes a second 200 kW ICRF unit for heating the center cell, and spare parts for the ECH system. The remaining $700,000 is requested for spare parts needed for TMX-U operation, vacuum system equipment needed for maintaining and enhancing the TMX-U vacuum, and controls needed to vary the potential.

MIT - $1,000,000 (TARA)

These funds are requested to support the TARA MDF. Approximately $350,000 will be used for the magnet power supply, $300,000 for diagnostics and controls, and $350,000 will be used for items needed for the vacuum system.

U. of Wisconsin - $200,000 (Phaedrus)

These funds are requested to provide spare parts and replacement for items that need to be replaced in order to run the experiment.

UC-B - $80,000 (MMX)

These funds are requested to provide spare parts and replacement for items that need to be replaced in order to run the experiment.

Elmo Bumpy Torus Program

Q1.(a) What are the detailed FY 1981, FY 1982 and FY 1983 objectives, funding levels, and program milestones for the Toroidal and Mirror Confinement Systems subactivities of the OFE's Confinement Systems activity?

Objectives

MCS Elmo Bumpy Torus Program

The objective of the bumpy torus program over the next several years is to achieve proof-of-principle demonstration of the EBT concept. The principal program elements are: the operating EBT-S experiment at ORNL; the proof-of-principle device, EBT-P, now being designed; and the operating STM device at TRW. The major objectives for FY 1982-1983 are:

1. The completion of Title I design and a major portion of Title II design (including supporting R&D) in preparation for beginning construction of the Elmo Bumpy Torus Proof-of-Principle (EBT-P) device.

2. Continued investigation of basic physics issues on the existing EBT-S and STM machines, including:

   (a) Electron and Ion Heating
   (b) Transport Scaling
   (c) Stability of the Relativistic Electron Rings and Core Plasma
   (d) Ambipolar Potential Control and Modification
   (e) Impurity Behavior and Transport

3. Investigation of improvements to the EBT concept, including aspect ratio enhancement, modification of the ambipolar potential, and optimization of ring heating.

Elmo Bumpy Torus Program Funding Levels

Funding Levels	FY 1981	FY 1982	FY 1983
Total	16,474	27,411	15,920
Research Operations	9,199	12,100	14,000
Capital Equipment	1,875	1,865	1,920
Construction	5,400	13,446	0

Major EBT Program Milestones

FY 1981

- On EBT-S, continued favorable confinement scaling was demonstrated with microwave power increased to 200 kW at 28 GHz. A direct ion heating method with ICRH, scalable to EBT-P, was demonstrated.

- On EBT-P, a major study of alternative development paths for advancing the EBT concept was completed by ORNL/MDAC with the conclusion that the EBT-P reference design was the most cost effective approach available.

- A major physics checkpoint review of the EBT program was conducted. The senior review panel convened by DOE concluded that the data base for the EBT-P concept was sound and strongly recommended proceeding with EBT-P construction.

FY 1982

- Increase ICRH power to 100 kW in EBT-S, to extend data base for scaling. At this power, a large fraction of the ions will be heated to significant temperatures. The confinement of these hot ions, along with modifications on the ambipolar potential, will be addressed.
- Install split mirror coils which give diagnostic access to the mirror throat plasma in EBT-S. The plasma parameters in this spatial region have never been measured. The plasma profiles obtained will be a valuable input to the transport codes.
- Complete EBT-P Title I design. Title I design will be completed, and a 10 volume design report will be issued.
- Continue EBT-P Title II design. Title II design will continue, together with the required R&D support. Support activities will include the fabrication and testing of a prototype magnet; tests of 28 and 60 GHz microwave systems; tests of limiters, seals, and flanges; and development of diagnostics.

FY 1983

- Install and operate a second 28 GHz gyrotron on EBT-S. The second gyrotron will double the microwave power input capability so that scaling studies can be greatly extended. The second tube will also require the development of a system to operate the gyrotrons independently, which is an important feature needed for EBT-P.
- Obtain plasma density and temperature profile measurements in the mirror throats.
- Fabricate aspect ratio enhancement (ARE) coils to modify the magnetic field geometry in EBT-S. The dependence of confinement on aspect ratio enhancement is predicted to be strong and favorable.
- Heat EBT-S ions with high frequency ICRH. These experiments will follow the 100 kW ICRH experiments at 30 MHz in FY 1982, with higher frequencies of 40-50 MHz. The purpose of the higher frequency work is to optimize the coupling and heating.
- Continue EBT-P Title II design. Highest priority in the R&D program will be given to the magnet development program.

Q1.(b) Provide justification of how each of the tasks/subtasks/projects carried out in the Toroidal and Mirror Confinement Systems subactivities support stated objectives.

The following chart shows in matrix form how each of the budget tasks support the EBT program milestones as stated in the reply to question 1.(a).

Mirror Program Matrix

		TMX-U	Phaedrus	STM	MFTF-B	TARA	EBT-S	EBT-P
Status		Checkout	Operating	Operating	Under Construction	Construction About to Start	Operating	In Design
Unique Capability		Thermal Barriers	R.F. Tests	Hot Electron Stabilization	Breakeven Conditions	Axisymmetry	Only Bumpy Torus in U.S.	Proof of Principal Test
Physics Issue	Concept Improvement Issue							
Heating	Steady State R.F. & Beams		ICRH Research	ECRH Research	High Power Heating	Neutral Beam Design	Steady State ECRH-ICRH	High Frequency S.S. ECRH ICRH
Fueling	Pellet Injection Radial Diffusion or Axial Trapping		Axial R.F. Trapping		Radial & Axial Fueling Tests			Pellets Radial Injection
Equil. Stability	Axisymmetry Beta Limits Loss Cone Mode	Microstable End Cells		MHD Stability by Rings		Average Minimum B		Test Beta Limits
Perpendicular Transport		First Measurements			Major Scaling Experiment	Test Axisymmetry Effect	A.R.E. Coils	Major Test
Impurity Control	Not a Problem So Far	Test "Self Divertor" Action						Major Test
Self Heating	Alpha Particles				Particle Simulations Planned			
Electric Potential	Tandem Mirrors Axial E. EBT-Radial E	Thermal Barrier Tests	Axial Measurement		Radial Axial Profile Studies		Radial Profiles	Detailed Studies Planned
Parallel Transport	End Loss From Open Systems	End Loss Reduction by Thermal Barriers			Major Scaling Experiment			

Detailed operating plans for the major MCS bumpy torus facilities are as follows:

1) EBT-P

	FY 1982	FY 1983
Funding Levels: Total	10,600	4,000
Research Operations	4,000	4,000
Capital Equipment	1,200	0
Construction	5,400	0

The mission of EBT-P is to provide a proof-of-principle level demonstration of the viability of the EBT concept as an approach to magnetic fusion. Functionally, EBT-P is a significant scale-up in size and plasma conditions from the existing EBT-S experiment at ORNL and will address the major physics and technology issues involved with developing the concept.

During FY 1982 and FY 1983, no construction activities are authorized. The funding will be directed toward the completion of Title I design (essentially complete now), the continuation of Title II design, and provision for the requisite R&D support for Title II. The specific areas of R&D support include: magnets, microwave systems, machine development, diagnostic development, and physics support.

In the magnet area, at least one prototype magnet will be wound and tested in 3-magnet tests with the two completed developmental coils. A second prototype may be needed to qualify a second supplier of superconducting wire. A full coil installed in a dewar will not be necessary for the qualifying. With the microwaves, high power tests of the 60 and 28 GHz transmission systems will be made. The main machine development activities will involve limiter probe tests and tests of metal seal and flange designs for the toroidal vessel. The diagnostics and physics efforts will be closely coupled and will focus on the diagnostic requirements needed to implement the experimental program being developed by the physicists.

By the end of FY 1983, it is expected that Title II design will at least be well along toward completion so that if the future years funding outlook changes, meaningful construction activities could begin immediately and minimize the slippage from the original schedule in which construction was to begin in FY 1982.

2) EBT-S

	FY 1982	FY 1983
Funding Levels: Total	8,755	10,020
Research Operations (for base and upgrade)	7,000	8,300
Capital Equipment	1,755	1,720

The mission of EBT-S has two aspects: first, the lead role among existing machines in developing the EBT concept; and second, to provide support for EBT-P. The first aspect includes broadening the physics base of the concept, testing methods to improve the concept, and developing the pertinent technological hardware. The physics and technology arising from the EBT program have also been of significant interest for application in the tandem mirror and tokamak programs. The second aspect includes testing and development of methods and components planned or considered for use on EBT-P.

During 1982 and FY 1983, significant efforts will be made on advancing the concept in the four key areas, viz. heating, transport, ring physics, and the physics and technology of high power heating. High power ICRH will be done not only to study the effects of large amounts of direct ion heating, but also to test high power antenna designs and ICRH transmission systems. Some of the effects may be important for improved ion confinement in addition to the heating. EBT-P will rely heavily on ICRH to attain one of its major objectives, a 5% core plasma beta. The ECRH capability will be doubled with the installation of a second 28 GHz gyrotron. This will be important to determine whether the favorable transport scaling continues at higher microwave powers. The second gyrotron will also be used in tests of EBT-P 28 GHz microwave components. The work will also test methods of operating the gyrotrons independently which is a requisite for EBT-P. Coils to modify the magnetic field will be fabricated. These coils for aspect ratio enhancement are predicted to improve confinement. Several alternative modes of machine operation and new techniques will be studied, evaluated, and tested, where possible. These alternatives and new techniques are expected to be very beneficial for confinement. Finally, with respect to transport, new coils which will permit diagnostic access to the mirror throats will be fabricated and installed. A strong program to improve the diagnostics for measuring the energy distribution, including spatial dependence, of the stabilizing relativistic electron rings is under way. The enhanced diagnostic capability for the rings and mirror throats is important for the experimentalists to understand plasma behavior and for theorists to construct more realistic models. In heating technology, the previously mentioned ICRH antenna, ECRH and ICRH transmission systems, and limiter probe studies will be the foci of activity.

Many of the programs cited directly support EBT-P viz. the ICRH has been discussed, the transport scaling provides input for extrapolating to EBT-P, the two-gyrotron operation has been discussed, and the limiter probe effort will include EBT-P prototypes.

By the end of FY 1983, the EBT-S program will have applied significant amount of direct heating to the ions via ICRH, extended transport scaling into higher ECRH regimes, greatly enhanced the knowledge of plasma and ring behavior by direct measurements, evaluated and tested, where possible, alternative modes of operation which could significantly improve performance, and have ready for installation aspect ratio enhancement coils to test a major EBT scaling law.

3) STM

	FY 1982	FY 1983
Funding Levels: Total	1,210	1,500
Research Operations	1,100	1,300
Capital Equipment	110	200

The role of STM is to provide direct support to the EBT and tandem mirror programs. STM has developed a unique approach using multiple frequency ECH (MFECH) to form and control relativistic electron rings similar to those which stabilize an EBT. The approach is also relevant for tandem mirrors in studying ways to construct, if possible, a symmetric tandem mirror which would have far simpler technology requirements and much better confinement than conventional systems. Specific important issues which STM will address are: for EBT, testing the limits on the core plasma parameters which can be stabilized by rings; for tandem mirrors, testing methods to form thermal barriers.

In the first half of FY 1982, the newly constructed STM-1 device will be operated extensively with all available microwave and ICRH sources to determine if the performance matches or exceeds design expectations. Of particular interest will be studies to measure improvements in ring parameters over those achieved in the SM device in which initial MFECH work was done. A substantial effort will be made to understand and document the physics details of ring formation and the means of control. The second half of FY 1982 will have two thrusts. First, the experimental objective is to attain a "disk" of relativistic electrons, as opposed to the usual rings. Such an achievement would be of direct benefit to the tandem mirror program for thermal barriers. Second, machine modifications would be developed and proposed to DOE. These modifications would permit STM to attain a core plasma beta of 5%. This would be very significant for EBT in that its attractiveness as a fusion concept is based on the belief that steady-state high beta core plasmas can be stabilized by the rings. Achievement of a beta of 5% would greatly increase confidence in that belief, even though STM is an open device and it differs from the toroidal EBT. This stability demonstration is important also to symmetric tandem mirrors stabilized by hot electron anchors. The experimental objective for FY 1983 would be to attain the 5% core beta.

By the end of FY 1983, STM will have resolved the following issues: the feasibility of forming hot electron disks for use in thermal barriers, whether intermediate core beta plasmas can be stabilized by rings, and how the rings are formed and methods to control them.

Q1.(d) Provide detailed justification and funding levels for the FY 1983 request of $21.8 million for Confinement Systems capital equipment.

Capital Equipment Funds (B/A)	FY 1983
Confinement Systems	21,800
Mirror Confinement Systems	6,200
EBT Program	1,920
ORNL (EBT-S)	1,720
TRW (STM)	200

ORNL - $1,720,000 (EBT-S)

For EBT-S, the equipment funding will support activities including:

- diagnostics and data acquisition systems for plasma temperature and density measurements in the mirror throats, and spatially resolved measurements of ring parameters (about $470,000);

- power supply for the second 28 GHz gyrotron and microwave transmission system components (about $820,000); and

- equipment for routine machine upkeep and maintenance (about $430,000).

TRW - $200,000 (STM)

For STM, the equipment funding will support activities including:

- 18 GHz klystron systems including tubes, power supplies, and transmission systems. To attain the 5% beta objective, higher fields will be needed and hence higher frequency microwave sources (about $100,000);

- machine modifications needed to accommodate the higher microwave frequency and power (about $50,000);

- upgraded diagnostic capability including a heavy ion beam probe to measure the ambipolar potential (about $50,000).

Mirror Fusion Test Facility-B

Funding Level ($ in thousands)	FY 1982	FY 1983
Operating Expense	9,150	6,000
Equipment Expense	0	0

The MFTF-B project is the largest and most advanced fusion device in the mirror program. Its objectives are to demonstrate plasma confinement, densities, and temperatures which are in or near the reactor regime, and to provide significant technological tests in the areas of reactor scale superconducting magnets, quasi-steady state (30 sec) neutral beam heating systems, and high vacuum pumping.

The original MFTF project was authorized as a single mirror device in FY 1978. However, in response to a succession of experimental and theoretical advances with tandem mirror systems, the Congress approved a request to rescope the project as a tandem mirror device, MFTF-B, in FY 1981. In late FY 1981 and early FY 1982, the original MFTF single mirror systems, including the vessel, vacuum, computer controls, cryogenic and superconducting Yin-Yang magnet systems, were completed and successfully tested under full design conditions. All systems performed well. The Yin-Yang magnet test was particularly noteworthy and has received international acclaim because it is the largest superconducting magnet in the world (weighing 375 tons, with 31 miles of superconductor, 5,775 amperes of current, and 450 megajoules of stored energy). This magnet operates at 4.5 Kelvin (451.6°F below zero) and creates a magnetic field at the conductor of 70,000 Gauss (which is 150,000 times greater than the earth magnetic field) while requiring only 100 watts of power in the magnet.

In FY 1982 and FY 1983, design and fabrication is under way on all the major MFTF-B facility systems which require modification and expansion for the tandem configuration; these include the new superconducting magnets, vacuum vessel, cryogenic system, vacuum pumping system, computer systems, building and structure. The major portion of funding is being provided from the construction budget appropriations ($39.9M in FY 1982 and $40.0M in FY 1983). Project completion is scheduled for June 1986 and experimental operations will begin at that time. This schedule contains a nine-month slip from the dates provided Congress in the Department's FY 1982 budget because of a $25M budget reduction in the proposed funding for FY 1983 ($46.5M vs. $40.0M in plant and $24.5M vs. $6.0M in operating).

The operating expense budget for MFTF-B in FY 1982, FY 1983 and through project completion in FY 1986 provides R&D support, preparations for operations, and auxiliary components for the device. The major effort planned for the $24.5M FY 1983 budget level was associated with design and procurement of the auxiliary components including such items as ECRH gyrotrons, neutral beam sources, magnet liners and diagnostic equipment. Contracting and initiation of fabrication of these items will be deferred to FY 1984. It is this approximate one-year delay in providing auxiliary components required for experimental operations, that is the primary course of the overall delay in the project.

Q2.(a) What are the detailed FY 1981, FY 1982 and FY 1983 objectives, funding levels, and program milestones for the subactivities of the OFE's Development and Technology activity, including 1) Magnetics, 2) Plasma Engineering, 3) Fusion Reactor Materials, 4) Fusion Systems Engineering, 5) Environment and Safety, and 6) Fusion Energy Applications?

1) MAGNETICS

Funding

The Magnetics Systems Funding levels are:

	FY 1981	FY 1982	FY 1983
		(BA in Million of $)	
Large Coil Program	$ 15.6	$ 20.7	$ 13.8
Operating	7.3	11.3	11.2
LCTF Capital Equipment	1.8	3.4	2.6
LCTF Construction	6.5	6.0	0
High Field Conductor & Magnets	6.5	4.3	5.4
Operating	4.2	2.8	4.5
Capital Equipment	2.3	1.5	.9
Pulsed Magnets	2.2	1.6	1.1
Operating	1.9	1.5	1.0
Capital Equipment	.3	.1	.1
TOTALS	$ 24.3	$ 26.6	$ 20.3

The LCP with its six coils, three of which are from international participants, will represent an investment of $100 million. The LCTF construction and capital equipment costs roll-off in FY 1983 and FY 1984, but are partially replaced by the increased costs to operate the facility.

Objectives

Magnetic fusion reactors require high steady state and controllable magnetic fields to confine the hot reacting plasma. These magnetic fields have to be produced with a minimal electrical input in order to achieve a favorable overall power balance of a fusion plant. Fortunately, the use of superconductors which have no electrical resistance at liquid helium temperatures (4°K) can meet this stringent requirement. The Magnetics subactivity develops superconducting technology and designs, builds, and tests superconducting magnets with the overall objective of demonstrating the technology readiness to fabricate the superconducting magnet systems that will be needed for current and planned fusion devices. A vital accompanying objective is to develop the capability of private industry to design and manufacture the superconducting magnets. The principal high priority tasks that are underway are the Large Coil Program, High Field Superconductor and Magnet development, and Pulsed Magnet Technology.

Milestones:

FY 1981

- Continue fabrication of General Electric, General Dynamics, and Westinghouse Large Coils
  - Complete verification tests of superconductor and structural weldments
- Continue construction of Large Coil Test Facility (LCTF)
  - Leak Test and accept vacuum vessel
  - Install bucking post and spider frame
- Test of 12 Tesla superconductor for High Field Test Facility (HFTF)
- Develop and test 12 Tesla superconductor for two high field coils to be tested in the HFTF
- Continue property measurements of structural steels and electrical insulators for 4°K operation
- Complete development and test 50 kiloampere low-loss superconductor for 20 MJ pulse coil
- Continue fabrication of Tokamak Poloidal Field System (TPFS) test facility at LANL

FY 1982

- Complete fabrication of General Electric and General Dynamics large coils
- Continue fabrication of Westinghouse coil; accept delivery of Japan coil
- Begin external instrumentation of General Electric and Japan coils
- Continue fabrication of LCTF
  - Install liquid nitrogen-cooled cold wall and test
  - Install Helium liquifier system and operate
  - Install three power supplies
  - Begin installation of large coils
  - Begin fabrication of pulse coil system
  - Order three more power supplies
- Complete 12 Tesla background coils for HFTF and operate facility
- Complete two 12 Tesla coils for testing in HFTF
- Continue advanced superconductor development and property measurements of magnet structural and electrical insulating materials for 4°K operation
- Stop fabrication of 20 MJ pulsed coil and TPFS test facility

FY 1983

- Complete fabrication of Westinghouse and General Dynamics coils, accept delivery of EURATOM and Swiss Coil, begin external instrumentation
- Complete external instrumentation of General Electric, General Dynamics and Japan coils
- Complete LCTF sufficient for three coil test
    - Install two or three large coils
    - Install torque beams and structural support
- Operate and shake-down LCTF with two or three coils
- Operate HFTF and test two high field coils
- Continue advanced superconductor and structural materials development
- Restart pulsed coil program if cooperative agreement with Japan reached

2) PLASMA ENGINEERING

Funding

The Plasma Engineering Funding levels are:

	FY 1981	FY 1982	FY 1983
		(BA in Millions of $)	
Positive Ion Neutral Beams	$ 3.441	$ 3.717	$ 3.550
Negative Ion Neutral Beams	2.077	1.403	2.400
Test Stand Operations	4.240	3.500	3.500
NBETF Upgrade (B/A Equipment)	(1.800)	(2.550)	(1.650)
Operations	0	0.900	1.345
Conventional RF Systems	0.071	0.550	1.325
Electron Cyclotron Resonance (ECRH) Heating	4.47	4.52	5.53
Pellet Fueling	0.500	0.550	0.600
High Heat Flux	0.150	0.670	1.000
Vacuum	0.300	0.250	0.350

Objective

In order to operate a fusion reactor, the plasma must be heated to high temperatures using auxiliary heating, fueled, and the energy in the plasma near the walls handled by high heat flux components. The plasma engineering task addresses needs in each of these areas as follows:

- The objective of the neutral beams and conventional Radio Frequency Heating system is to develop efficient plasma heating systems by use of neutral beam injections and radio frequency energy.

- The objective of the Electron Cyclotron Resonance (ECH) heating is to develop radio frequency power sources, and transmission system to provide power at higher frequencies and power levels as required by fusion experiments.

- The objective of the pellet fueling program is to develop reliable, high velocity solid pellet injectors for near term tokamaks on schedules consistent with user needs and for FED by the late 1980's.

- The objectives of the high flux program is to develop an engineering data base for the design of components (such as neutral beam dumps, plasma limiters and divertors) which require effective cooling of surfaces subjected to high heat fluxes.

- The objective of the vacuum program is vacuum--to develop vacuum components and vacuum measurement devices to support needs of current experimental confinement programs and future devices.

Milestones

Neutral Beams and Conventional Radio Frequency Heating

FY 1981

- Operate Scale Advanced Positive Ion Source at 80 KeV, 30 seconds, 100 KeV, 10 seconds and 120 KeV 1-1/2 seconds
- Operate full size Plasma Source for 30 seconds
- Demonstrate 80 percent atomic yield in full size TFTR source
- Demonstrate one ampere negative ion source
- Selection of Negative Ion Source Concept
- Initiate NBETF Project
- Finish High Power Test Facility Phase I Upgrade

FY 1982

- Operate full size Advanced Positive Ion Source at 80 KeV, 30 seconds in hydrogen and 80 KeV, one second in deuterium
- Demonstrate higher beam brightness required for MFTF-B
- Test improved atomic yield source (goal 90 percent atomic)
- Accelerate two amperes negative ions to 34 KeV
- Initiate design of one-to-two ampere 150-200 KeV negative ion accelerator
- Complete radio frequency technology development plan

FY 1983

- Operate full size Advanced Positive Ion Source (APIS) at 80 KeV, and 120 KeV 30 seconds in hydrogen and dueterium
- Complete NBETF project
- Operate one-to-two ampere, 200 KeV negative ion source
- Initiate design of 10 ampere negative ion source
- Initiate RF technology test facility design
- Initiate industrial phase of RF technology development

Electron Cyclotron Resonance Heating

FY 1983

- Complete development of a 60 GHz, 200 kW, cw gyrotron - September 1983

Pellet Fueling

FY 1982

- Complete initial development of centrifugal pellet injector with 1 km/s, 1-2 mm diameter pellets

FY 1983

- Complete initial development of gas-driven pellet injector with 1 km/s, 1-2 mm diameter pellets
- Complete conceptual designs of centrifugal and gas-driven, reactor-relevant pellet injectors

High Heat Flux

FY 1982

- Complete review of proposed FY 1983-87 Five-Year Plan
- Complete evaluation of initial experiments

3) FUSION REACTOR MATERIALS

Funding	FY 1981	FY 1982	FY 1983
	(BA in million of $)		
Operating	$12.165	$14.760	$15.700

Objectives

The objective of the Fusion Reactor Materials program is to identify and develop the materials, including metals, ceramics and polymers, that will be required to build the experimental test facilities and fusion power reactors. The activities focus on solving materials problems associated with extended exposure to an environment characterized by high temperatures and high energy neutrons and charged particles. A major aspect of the program is to evaluate the damage phenomena that occurs in the fusion environment to establish the basis for the engineering requirements for the design of fusion reactors. Materials that are being studied and developed include alloys with which to build the structures, ceramics to protect the alloys from high energy plasmas, inorganic compounds to breed tritium fuel and to convert neutron energy into heat, superconductors and insulators for confinement magnets, and coolants to extract the heat for conversion to electrical energy.

Milestones

FY 1981

- Completed the initial preparation of data sheets for the influence of fusion-like irradiation conditions on the properties and behavior of the structural alloys for the inclusion in the initial edition of the Materials Handbook for Fusion Energy Systems

- Initiated the scale-up of a long-range ordered alloys which have potential for long-term, high performance applications to the fusion reactor systems, a scale-up from laboratory quantities to methods that are appropriate for industrial production of this promising category of radiation resistant alloys

- Initiated a program of collaboration in irradiation damage studies with the European Community (EC) and with Japan under the auspices of the IEA Implementing Agreement on a program of experimental studies of Radiation Damage to Fusion Reactor Materials. A second annex of this IEA Agreement provides for international collaboration contributions to the design and construction phase of the FMIT facility at the Hanford Engineering Development Laboratory (HEDL). Personnel of the EC were assigned to that project during this time period

- Completed first fission-fusion correlations for stainless steels

- Identified critical parameters for the effects of helium on grain boundary embrittlement

- Initiated irradiation testing of polyimide organic insulators for fusion magnets
- Initiated irradiation testing of blanket breeder materials
- Completed the scoping test evaluation of the path-B, Fe-Ni-Cr alloys, and select the leading path-B alloys for further development in the ADIP program
- Initiated a joint U.S./Japan program in the study of the irradiation response of the fusion structural alloys
- Characterized the thermal aspect of plasma disruptions in tokamak via post exposure materials analysis
- Established the expected tritium inventory and permeation characteristics of TFTR and FED/INTOR using the diffuse code
- Characterized the plasma boundary region in ISX, PLT and TMX using solid state probes and nuclear analysis techniques

FY 1982

- Two leading mechanical and thermal treatments for the alloy PCA for the second phase irradiation testing; i.e., for the initial step in experimentation to establish an optimum treatment and composition for this alloy category
- Complete the initial assessment of the influence of radiation damage on the fracture behavior of the ferritic stainless steels. This will provide an early guide as to the potential suitability of that class of alloys for the fusion reactor applications.
- Complete the scoping test evaluation of the Path-B, Fe-Ni-Cr alloys, and select the leading Path-B alloys for further development in the ADIP program
- Initiate a joint U.S./Japan program in the study of the irradiation response of fusion structural alloys
- Determine critical life-limiting component of fusion superconducting magnets
- Initiate irradiation testing to determine the difference between neutron and gamma effects in organic insulators
- Develop and test thick (1-2 mm) coatings of low-Z materials for plasma interactive components
- Complete the initial characterization of the chemical interaction of graphite to plasma irradiation over the temperature range of 1200° to 2000°K

- Complete the design and manufacture of an advanced pumped limiter module for TEXTOR
- Initiate irradiation testing in cooperation with the EC and with Japan using U.S. and European test facilities as part of the IEA Implementing Agreement on a program of radiation damage to fusion reactor materials

FY 1983

- Complete irradiation testing of polyimide organic insulators
- Complete irradiation testing of N_3Sn and N_bTi superconductors
- Characterize RTNS-II large target-produced spectrum
- Complete free defect production studies
- Complete first long-term irradiation on structural materials in RTNS-II
- Complete the initial three-year evaluation of the suitability of the use of ferritic stainless steels for fusion reactor systems. This will include consideration of a recommendation for the potential use of that alloy class in near-term fusion reactor systems.
- Complete the scoping phase evaluation of the Path-A alloys, PCA and 316 stainless steel including consideration of radiation damage levels equivalent to the near-term fusion reactor concept and establish the basis for alloy selection for those concepts

4) FUSION SYSTEMS ENGINEERING

	FY 1981	FY 1982	FY 1983
Funding		(B/A in millions $)	
Operating	$10.722	$ 11.120	$ 17.100*

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*Includes $5 million of funding for Fusion Engineering Device activities. This funding was in a separate budget category in FY 1981 and FY 1982.

Objectives

The overall objectives of Fusion Systems Engineering are to project fusion reactor technological and economic targets through reactor design and analytical studies as guidance for magnetic fusion development, and to develop the major nuclear subsystems needed for fusion reactors. Objectives for individual sub-activity elements are given below.

In the area of reactor conceptual design studies and assessments, the objectives are to make technological and commercial feasibility assessments of various fusion reactor concepts by designing commercial-sized reactors; provide a realistic baseline for fusion reactor subsystem designs; and to identify data and performance requirements for plasma confinement and technology development which can be used in planning future program directions.

The Blanket and Shield Engineering element covers the development of fusion reactor blanket and shield systems. The program objective is to provide a technology base for structural, thermal, electromagnetic, nuclear and tritium breeding design of first wall, blanket and shield components and systems. In the near term, the program will emphasize support of the FED design and will develop the prerequisite data base for DEMO and commercial fusion reactors.

The objectives of the Tritium Processing and Control element are to develop and demonstrate the technology base for operating a prototypic fusion reactor fuel cycle system and to demonstrate the ability to control, contain and safely handle reactor-relevant quantities of tritium.

Milestones

FY 1981

- Complete Elmo Bumpy Torus (EBT) Level I Commercial Reactor Design Study
- Complete SATYR study of D-D Fueled Tandem Mirror Reactor and WILDCAT study of D-D fueled Tokamak reactor to provide input for assessment of the viability of advanced fuels
- Complete preliminary conceptual study of a commercial Modular Stellarator Reactor (MSR)
- Complete selection of the end-plug concept for the commercial tandem mirror reactor study
- Complete evaluation of supplemental plasma heating systems for tokamaks by comparing radio frequency heating with neutral beam heating
- Complete contracting of First Wall, Blanket and Shield Engineering tasks through ANL, which serves as lead technical organization
- Complete design specifications for tritium breeding TRIO-01 experiment containing $LiAlO_2$
- Complete first experiment on neutron streaming through shielding ducts
- Initiate testing of prototypic tritium monitor which differentiates on a real time basis between tritium gas and tritiated water

FY 1982

- Complete the design study for a tokamak reactor which will demonstrate features and subsystems extrapolatable to commercial use and show that the risk of developing a first commercial reactor is acceptable (STARFIRE DEMO)
- Complete preliminary assessment of reactor designs which use materials that have low induced radioactivity properties
- Complete optimization of magnetics design of Modular Stellerator Reactor study
- Complete definition of Compact Reverse Field Pinch Reactor design point
- Begin first wall component testing under simulated surface heat fluxes at ESURF facility and complete larger ASURF facility
- Initiate in-pile irradiation of TRIO-01 experiment
- Initiate nuclear data evaluation program
- Complete construction and begin initial operation of the Tritium Systems Test Assembly (TSTA)
- Initiate experimental program at TSTA

FY 1983

- Complete the Mirror Advanced Reactor System Commercial Design Study (MARS)
- Complete the Modular Stellerator Reactor Commercial Design Study
- Complete Compact Reverse Field Pinch Reactor Study
- Complete construction of FELIX electromagnetic effects test stand
- Complete TRIO-01 testing and design specifications for TRIO-02 experiment
- Complete second experiments on neutron streaming through shielding ducts
- Demonstrate full-scale steady-state, integrated closed loop operation of fusion reactor D-T fuel cycle

In FY 1983, the funding for the activities associated with the Fusion Engineering Device (FED) have been relocated from the discontinued Center for Magnetic Fusion Engineering budget category into the Fusion Systems Engineering subactivity. The purpose of this activity is to determine what the next major device in the magnetic fusion program should be, design the device, perform necessary supporting technology development and construct and operate the device. This device, the FED, would serve as the principal element in the program which will demonstrate the engineering feasibility of fusion energy. This demonstration, in conjunction with information from the ongoing fusion plasma physics research program will provide the basis for construction of a fusion demonstration plant.

The milestones in the FED activity are as follows:

FY 1981

- Complete and document the initial FED preconceptual design
- Document the proposed U.S. approach to demonstrating the engineering feasibility of magnetic fusion

FY 1982

- Continue engineering evolution of the conventional tokamak FED documented in FY 1981 to develop means of reducing costs and improving performance
- Investigate high leverage physics improvements to the conventional tokamak approach, such as steady state tokamak operation with current drive
- Investigate alternatives to the conventional tokamak FED, such as:
    a) A mirror-based Technology Development Facility (TDF)
    b) A copper magnet, high field tokamak technology test device

FY 1983

- Prepare an updated tokamak FED preconceptual design incorporating the results from the engineering and physics improvement development work done in FY 1981
- Select the most promising alternative approach identified in FY 1981 and continue development of this concept by investigating the critical issues and potential innovations applicable to this approach
- Potentially, initiate an international assessment of the potential for a mirror-based TDF if the FY 1982 results are favorable

5) ENVIRONMENT AND SAFETY

Funding

FY 1981	FY 1982	FY 1983
	(B/A in millions of $)	
$ 2.086	$ 2.795	$ 2.900

Objectives

The objective of the Environment and Safety Program is to assure that the development and operation of fusion facilities are accomplished with minimal adverse effects in the environment and with maximum safety for both the public and for DOE personnel and property. Also managed out of the Environment and Safety category are the Fusion Engineering Educational Programs. These include the Magnetic Fusion Energy Technology Fellowship Program (MFETFP), currently supporting 12 fellowships, and the Fusion Engineering Research Residences in Industry, each year supporting five student appointments for six-month periods at a major fusion industrial contractor. The objective of these programs is to produce a relatively small number of very high quality graduates in fusion engineering disciplines as a resource for future technical leadership.

Milestones

FY 1981

- Complete safety scoping tests on liquid lithium fires
- Award first six fellowships in the Fusion Technology Fellowship Program
- Award six additional fellowships in the Fusion Technology Fellowship Program

FY 1982

- Initiate experiments on release mechanisms for activated products and verification of analytical models for different accident scenarios
- Initiate small-scale magnet safety experiments
- Initiate development of codes which determine the magnitudes, chemical form and location of released tritium
- Award six additional fellowships in the Fusion Technology Fellowship Program

FY 1983

- Initiate extensive safety testing on selected blanket concepts
- Complete Generic Environmental Impact Statement
- Award final six fellowships in the Fusion Technology Fellowship Program

6) FUSION ENERGY APPLICATIONS

Funding

FY 1981	FY 1982	FY 1983
	(B/A in million of $)	
$ 1.700	$ 1.900	$ 2.200

Objectives

The objectives for the Fusion Energy Applications subactivity are to identify and demonstrate the technical, economic and environmental feasibility of fusion energy applications alternate to direct production of electric power generation. At present, activity in this area is limited to investigations of chemical (synthetic) fuel and fissile fuel production.

Milestones

FY 1981

- Complete Scoping Design Study of Tandem Mirror Hybrid Reactor based fission-suppressed blanket concept
- Complete and operate High Temperature Electrolysis demonstration unit

FY 1982

- Choose reference blanket concept and complete reference design of a commercial hybrid reactor based on fission-suppressed blanket
- Complete reference designs of fusion chemical fuel production plants based on high temperature electrolysis and thermochemical cycle concepts

FY 1983

- Integrate fusion-fission hybrid blanket neutronics and nuclear data activities into ongoing blanket and shield engineering program activities
- Determine viability of incorporation of chemical fuel production capability into Mirror Advanced Reactor Study (MARS), based on previously completed reference designs

Q2.(b) Provide justification of how each of the tasks/subtasks/projects carried out in the Development and Technology subactivities support stated objectives.

A 1) MAGNETICS

The international Large Coil Program (LCP) is the major effort of the Magnetic Systems subactivity. LCP is a tokamak-oriented program (but with broad generic components) centered at the Large Coil Test Facility (LCTF), a line item facility under construction at Oak Ridge National Laboratory (ORNL). Six large superconducting coils of 8 Tesla field are now being built by large industrial firms--three in the United States and three by foreign participants under an Internation Energy Agency (IEA) cooperative agreement--for testing and evaluation at LCTF.

The High Field Conductor and Magnet Development task supports development and industrial production of full-sized advanced conductor and structural materials for high field (12 Tesla) magnets for mirror and tokamak applications. Much of the testing will be done at the High Field Test Facility (HFTF), located at Lawrence Livermore National Laboratory (LLNL), which is now being modified to provide a high field testing capability.

The Pulsed Magnet Technology task is developing the components and systems necessary to produce special magnetic or electrical fields which initiate heat or control plasma. The fabrication of a pulsed 20 megajoule coil and the Tokamak Poloidal Field Test Facility (TPES) at Los Alamos National Laboratory (LANL) to demonstrate the technology for a Tokamak Ohmic Heating system has been the major task, but it has been decided to sharply curtail this effort in FY 1983 because of higher priority budget needs in the Large Coil and High Field Magnet tasks. However, efforts are underway to explore possibilities of cooperation with Japan to obtain this needed technology.

The Magnetics tasks are all aimed at directly achieving the objectives of developing the necessary technologies and demonstrating taht technology through design, fabrication and testing of hardware that is sufficient to demonstrate the technology readiness to fabricate the reliable superconducting magnet systems that will be needed for current and planned fusion devices. Substantial investments have been made in facilities and hardware which will demonstrate that the necessary superconducting magnets that need to be fabricated for fusion devices are, indeed, credible.

2) PLASMA ENGINEERING

Task: Plasma Heating
Subtask: Electron Cyclotron Resonance (ECR) Heating

The plasma performance of many confinement approaches can be substantially improved or is directly dependent on heating of plasma electrons. Use of ECR to heat electrons is a well understood and efficient process; however, large quantities of radio frequency powere were not available until the Office of Fusion Energy (OFE) undertook development of a relatively new power source, the gyrotron. Varian Associates, under subcontract to ORNL completed development of a 28 GHz, 200 kW, cw gyrotron in September 180 for the EBT-S device at ORNL. Earlier in 1979 as a result of widespread interest in the use of gyrotrons for more powerful experiments, OFE substantially increased funding for gyrotron development and initiated new programs in two areas: 1) industrial development of 60 GHz, 200 kW, cw gyrotrons for applications on PDX, D-III, MFTF-B and EBT-P, and 2) scientific research efforts to investigate gyrotron concepts for operation at 100 GHz at power levels of 200 to greater than 100 kW's.

In the first area OFE directed ORNL to award two subcontracts for the development of 60 GHz, 200 kW, cw gyrotrons. The purpose of the multiple award is to broaden the industrial base for supplying fusion program needs, reduce program risk and foster competition. ORNL awarded subcontracts to Hughes Aircraft and Varian Associates, both in California. Hughes, by virtue of its late entry into the field and restricted budgets, is behind Varian in development. However, it is likely that Hughes will be well established by the end of FY 1983.

In the scientific area, programs at the Massachusetts Institute of Technology (MIT) and the Naval Research Laboratory (NRL) are funded to investigate higher frequency and power operation with short pulses. Although these efforts do not produce deliverable hardware, they do provide scientific support to the industrial groups in the form of new theories and concepts which help explain the operation of gyrotrons under development. The present plan is to complete by the end of FY 1984 scientific research in support of an industrial effort to develop a 100 GHz, 1 MW gyrotron to begin in FY 1985. No major test equipment is required for the scientific efforts.

Task: Plasma Heating
Subtask: Neutral Beam and Conventional RF

Neutral beam heating involves the information and injection of streams of high-energy hydrogen or deuterium atoms into plasmas. The Neutral Beam Systems task is developing longer pulsed, higher energy, higher efficiency, and higher reliability advanced positive ion sources for use of TFTR, MFTF, Doublet-III, and future experiments such as ATF. The Neutral Beam Systems task is also devleoping negative ion based neutral beam systems which should provide the capability of operating at higher energies with increased efficiency. Such systems are expected to be sufficiently energetic to drive the current in a tokamak in steady state operation.

A new activity has been added to develop the technology for heating plasmas at more conventional RF frequencies (VHF and UHF) based on ion cyclotron and lower hybrid resonant heating. Most of the equipment for heating by these techniques is available commercially; however, there are certain areas where technology development is needed. These areas are mostly associated with the plasma interface where the RF waves are launched. A detailed, comprehensive planning activity is underway in FY 1982 to identify the key technology issues that need to be addressed by the development and technology activity. While some technology development is proceeding in FY 1982, it is expected that most of the actual technology development will commence in FY 1983.

The full scale advanced positive ion neutral beam sources have been assembled in an 80 KeV configuration for MFTF-B 30 second operation. Testing of the full scale sources has commenced. Testing of scale sources at MFTF-B parameters have demonstrated the desired performance. One method of increasing atomic yield in the base TFTR source has been successfully demonstrated and another method that promises even higher atomic yield has been tested in scale versions.

Negative ion neutral beam sources have been operated at 1 ampere, 34 KeV for several seconds. Testing at this level will continue through FY 1982 to optimize performance before fabricating a 10 ampere source.

Tests of ICRF antennas and feedthroughs will continue on PLT and the PLT test stand. A comprehensive development plan is under preparation.

Task: Plasma Fueling
Subtask: Pellet Fueling

One of the important parameters in confinement research is plasma density. High velocity injection of small pellets of solid hydrogen has been demonstrated to be an effective method for increasing plasma density. In addition, pellet fueling will be an effective means of maintaining plasma density in devices with impurity control and plasma exhaust removal systems such as divertors or pumped limitors.

Pellet injector development for OFE is performed by ORNL. The effort was initiated in 1975. Initial experimental injectors were available several years later and were used to perform density control experiments on ISX and PDX. The advanced mechanical injector now under test will be used on PDX in mid-1982. The advanced gas-driven injector will be available for use in early 1983. A preliminary conceptual design effort will be initiated in mid-FY-1982 to define the development program for injectors needed for next generation fusion experiments such as FED. Equipment funds are used for test equipment, vacuum pumps and motor required for pellet injector fabrication and testing.

Task: Vacuum and Particle Collection Systems
Subtask: High Heat Flux and Vacuum

One of the challenges of fusion research is to prevent melting and minimize the material damage and erosion that occurs due to high energy particles from the plasma hitting the surface of components inside the vacuum vessel. The High Heat Flux Program was initiated in mid-1981 to address this need for long pulse and steady state applications where active cooling of surfaces in contact with a plasma will be necessary. In particular, plasma researchers have identified the need for plasma limiters which can be cooled steady state at 500 W/cm^2 as well as withstand plasma disruption heat fluxes of up to 300 kW/cm^2 for brief periods. Development of designs to withstand these conditions is the highest priority for the program.

A low level of support is provided for vacuum technology development. Within these limits alternate methods of vacuum pumping have been explored to determine effective designs for FED and reactor applications. A small effort is supported at the National Bureau of Standards (NBS) to develop better methods and hardware for accurate determination of vacuum pressures. More accurate measurements will benefit many research activities in the fusion program.

3) FUSION REACTOR MATERIALS

The Fusion Reactor Materials Program supports the Magnetic Fusion Program in four major efforts. The first effort is the study of the detailed impact of 14 MeV neutrons and other high energy ions on the various materials used to construct and fabricate the fusion reactor. The objective is to understand the phenomena that occur from these interactions and to use this base of information to identify those materials that are resistant to detrimental phenomena and that could survive the fusion reactor environment. The second effort addresses the interaction between the hot plasma and the materials that will be used to contain and shape it. The objective here is to define the materials that can withstand the excessive temperatures, the high erosion rates and will recycle the tritium fuel. The third area is the development of the structural materials that can withstand the elevated temperatures, the high neutron fluxes and the large magnetically induced loads. The last area is development or characterization of the specific materials such as electrical insulators, electrical conductor stabilizers, tritium breeders and others.

4) FUSION SYSTEMS ENGINEERING

In the area of reactor conceptual design studies and assessments, major projects completed in FY1981 include the Elmo Bumpy Torus (EBT) Commercial Reactor Design Study, and studies of D-D fueled tokamak and tandem mirror reactors. The EBT study highlighted the importance of certain critical confinement issues such as ring power balance and Beta limits, which provide important guidance to near-term physics experiments and EBT-Proof-of-Principle (EBT-P) design. The D-D fueled reactor studies provided essential reactor design information to the alternate fuels assessment being carried out by the Alternate Concepts Branch of the Division of Applied Plasma Physics. In FY 1982, the STARFIRE DEMO tokamak reactor study is being completed to provide guidance for FED design and for longer range program planning. An assessment of low activation material use in reactor design is being continued in FY 1982 to provide input to decisions on whether to initiate more formal development programs for such materials.

In FY 1983, the Mirror Advanced Reactor Study (MARS) will be completed, providing a major evaluation of the technological and economic attractiveness of a Tandem Mirror Commercial Reactor. This study will be a prime source of information for continued tandem mirror development, highlighting such areas as end cell concept, thermal barrier design, alternate end cell pumping techniques and use of high field coils. Other projects being carried out in this program element are similarly providing important information to the ongoing technology and physics programs.

The blanket and shield comprise two of the major systems of any fusion reactor. The technology base needed for design of blanket and shield components and systems is in the early stages of development and a substantial program of experiments and analysis is required before design uncertainties can be resolved to the point that designers may proceed with confidence that blanket and shield performance requirements can be adequately met. The subelement on blanket and shield engineering development and testing will focus on systems development of first walls, blanket and shields for removal, transfer and practical utilization of fusion plasma energy in order to select from among fusion reactor design studies those candidate design concepts satisfactory for further development. The subelement will include tests to address the thermalhydraulic, thermomechanical and electromagnetic performance of candidate concepts and will develop a technology for assembly, maintenance and repair of these concepts. The subelement on tritium breeding and extraction systems development focuses on one of the major issues associated with the viability of solid breeders: recovery of bred tritium under fusion reactor conditions. The TRIO experiment will be instrumental in identifying the key factors affecting tritium release and recovery in solid breeders for determining if solid breeders are capable of meeting their performance requirements. The subelement on neutronics and nuclear data development focuses on the need for accurate data and calculational methods necessary for the neutronics analysis of blankets and shields. Such analysis is fundamental to the design of blankets and shields. The current technology base for neutronics analysis is not adequate to meet the special needs of fusion reactors due to the uniqueness of neutron energy ranges and materials and the complexities of geometries involved. This subelement addresses key issues currently facing fusion reactor neutronics analysis, such as streaming of high energy neutrons through shield penetrations, and will greatly improve the technology base for neutronics analysis.

The major project of the Tritium Processing and Control element is the Tritium Systems Test Assembly (TSTA) scheduled to complete construction and begin operation in 1982 at LANL. The TSTA will develop, demonstrate and interface the technologies related to the deuterium-tritium fuel cycle for fusion reactor systems. Most of the technical and operational problems of closed loop steady state fuel cycle operation, including maintenance, decontamination and decommissioning will be addressed in the TSTA. In addition to demonstrating the performance and safety of the overall system, this facility will be used to test and qualify components, including reliability testing for tritium service, as well as to conduct subsystem experiments. These experiments will include developing and demonstrating cleanup and control techniques, evaluating alternate processing schemes, and developing a required base of information on tritium behavior and properties. In addition to TSTA, there are two other projects being carried out in tritium technology development. One is the development of a tritum monitor which is capable of differentiating, on a real-time basis, between tritium gas and tritiated water. The other activity is directed toward development of improved methods to control, clean up and store tritium from accident situations.

5) ENVIRONMENT AND SAFETY

There are three areas of concern which this program element addresses: (1) identification and evaluation of potential hazards related to the operation of fusion facilities; (2) developing appropriate safety technology to control such hazards; and (3) performing environmental assessments and safety analysis of all major fusion facilities to assure that environmental impacts and facility safety implications are fully evaluated. Because of the overall importance of environmental and safety considerations in developing an energy technology, and the need for these considerations to be factored into the construction and operation of fusion facilities, this program is responsible for developing the safety information base which provides support to all other activities within the program: currently this program is divided into two categories. The first category is Reactor Safety Research, which is concerned with identifying, evaluating, and controlling all potential hazards associated with fusion energy development. Important research being conducted in this area includes the development of methods for controlling radioactive inventories (tritium and activation products) under both normal and accident conditions, understanding and developing appropriate protective systems for potential accident initiating sources (superconducting magnets, plasma, lithium) and the development of analytical tools (models, codes) which enable us to understand better the safety implications of fusion technology.

The second category is Environmental Assessment which is responsible for assuring that the environmental impacts of fusion energy development are identified and properly evaluated. Presently, the major effort in this category is toward meeting the programmatic goal of completing a Generic Environmental Impact Statement on the Magnetic Fusion Program in FY 1983 to support a DOE decision in the 1983-1984 time frame to accelerate fusion engineering development in accordance with the Magnetic Fusion Engineering Act of 1980.

6) FUSION ENERGY APPLICATIONS

Projects underway in this program element include reactor and system studies and minor experimental evaluations. The Tandem Mirror Hybrid study being carried out in FY 1981 and FY 1982 will provide information on important questions regarding technicl feasibility, cost and safety/environmental issues for the production of fissile fuel using the fission-suppressed fusion blanket concept. In FY 1983, hybrid work will be expanded into blanket neutronics and other blanket engineering development activities as part of ongoing programs in these areas. Also in FY 1981 and FY 1982, fusion reactor design studies are being carried out on concepts for production of hydrogen as an essential ingredient in coal conversion or for direct use as gaseous fuel. Technical and economic feasibility are being investigated both for thermochemical and high temperature electrolysis processes, and for both tokamak and tandem mirror fusion drivers. A small-scale high temperature electrolysis unit has demonstrated the fundamental feasibility of certain key aspects of this process for hydrogen production.

Q2.(c) Provide the detailed operating plans, including FY 1982 and FY 1983 funding levels, for each current or planned facility supported by the Office of Fusion Energy's (OFE) Development and Technology activity, including as a minimum 1) the Large Coil Test Facility (LCTF), 2) the High Field Test Facility (HFTF), 3) the Tritium Systems Test Assembly (TSTA), 4) the Rotating Target Neutron Source (RTNS-II), 5) the Neutral Beam Engineering Test Facility (NBETF), and 6) the Gyrotron Test Facility.

A 1) LARGE COIL TEST FACILTIY

Funding

	FY 1982	FY 1983
	(B/A in millions $)	
Operating	$ 2.7	$ 5.7
Equipment	3.4	2.6
Construction	6.0	0.0

Operating Plan

The LCTF will be completed in early FY 1984 with capability for testing six coils in a torus configuration and with pulsed field capability. The LCTF is scheduled for testing of some major components in FY 1982 and facility shake down with two or three coils in FY 1983. Twelve operators will be hired and trained in FY 1982 to operate the facility and will supplement the operations manager and shift supervisor personnel already assigned. A substantial part of the roll-off of construction and capital equipment costs will be required for operation of the facility in FY 1983 through FY 1986.

The operational costs are anticipated to plateau at between seven and eight million dollars per year in the FY 1984-86 time with the uncertainty due to the actual use of liquid nitrogen and liquid helium as each of the six coils goes through a rigorous test program to determine its superconducting stability limits and safety margins. A draft of the "Large Coil Task Test Program" is currently under consideration by the IEA Large Coil Task Executive Committee and can be provided if desired.

2) HIGH FIELD TEST FACILTIY

Funding

	FY 1982	FY 1983
	(B/A in millions $)	
Operating	$ 0.4	$ 1.3
Equipment	1.3	0.7

Operating Plan

The HFTF is designed to be a flexible facility to enable testing of full size high field superconductors for mirror and tokamak applications at magnetic fields up to 12 Tesla.

It is scheduled for completion in FY 1983, and it is planned to utilize this facility for possibly the next ten years. In FY 1983, full size conductor designed for a Mirror 12 Tesla Ying Yang coil will be tested as two separate coils and will remain as part of the facility. A 12 Tesla coil utilizing 150 meters of Nb$_3$Sn superconductor in a forced flow helium design will be tested as well as an 11 Tesla coil that will utilize a NbTiTa superconductor cooled to the 1.8°K Helium II or "superfluid helium" state.

3) TRITIUM SYSTEMS TEST ASSEMBLY

Funding

	FY 1982*	FY 1983
	(B/A in millions $)	
Operating	$ 2.6	$ 2.4
Equipment	0.4	0.1

*Construction of TSTA will be completed in April 1982.

Operating Plan

The initial operation of TSTA will begin in May 1982 with preliminary check-out and startup testing of individual subsystems utilizing only hydrogen and deuterium. This startup scenario will last for approximately two months at which time tritium testing will begin with the Isotope Separation System (ISS). Initial testing with tritium is expected to begin on all subsystems by the end of FY 1982. In FY 1983, integrated and continuous operation of the complete fuel cycle system will begin. In FY 1984-85, facility upgrades are planned to incorporate, for test and evaluation, improved capabilities for the Fuel Cleanup System to process tritium recovered from accidental cleanup operations and from solid breeder blanket materials.

The major details of the initial operating plan are as follows:

May-August 1982	-	Initial, phased, operation and detailed check-out of all systems and components with hydrogen and deuterium
July 1982	-	Initiate phased tritium check-out of all systems and components, beginning with the ISS
July 1982	-	Initiate performance evaluation of Fuel Cleanup System Catalytic Reactor and Hot Metal Bed processes
September 1982	-	Complete initial testing of all systems and components with tritium
September 1982	-	Initiate testing and evaluation of alternate main vacuum pumps
October 1982	-	Begin integrated and continuous operation of closed loop fuel cycle
April 1983	-	Initiate tritium cleanup experimental program using the Experimental Contamination Studies facility and associated systems

August 1983	-	Initiate Fusion Reactor Safety Research studies at TSTA on tritium release, absorption, conversion, and cleanup models, and on tritium measuring and monitoring systems

4) ROTATING TARGET NEUTRON SOURCE-II

Funding

	FY 1982	FY 1983
	(B/A in millions $)	
Operating	$ 2.0	$ 2.0
Capital	.15	.15

Operating Plan

The United States has entered into a joint agreement with Japan for shared support and utilization of the RTNS-II facility. Within the next three months, as specified in the Agreement, a detailed technical plan will be prepared by both Japan and the U.S., stating the specific experiments to be conducted in the forthcoming year. Both plans will have to be approved by the Joint U.S./Japan Steering Committee. The major topics to be considered in the U.S. plan include:

A. Engineering

  1. Existing Projects

    a. Tokamak Fusion Test Reactor components
    b. Fusion Materials Irradiation Test components

  2. Long Range

    a. Loss-tangent measurements on ceramic RF window materials
    b. Inorganic insulators to be used in neutral beam injectors
    c. Superconducting magnet materials

      (1) Nb_3Sn
      (2) Copper stabilizer material
      (3) Organic insulators

    d. Instrumentation components

B. Correlation

  1. Metals and Alloys

    a. Strength/ductility and microstructure
    b. Creep
    c. Microstructural/Microchemical Evolution
    d. Damage Production

  2. Non-metals

    a. Damage mechanism studies of organic insulators
    b. Low Z materials, especially graphite
    c. Solid breeder materials

C. Neutronics

A third class of experiments is neutronics, which includes neutron field mapping, dosimetry, cross section development, testing of transport calculations, etc.

5) NEUTRAL BEAM ENGINEERING TEST FACILITY

Funding

	FY 1982	FY 1983
	(B/A in millions $)	
Operating	$ 0.9	$ 1.3
Equipment	2.5	1.7

Operating Plan

The NBETF is a long pulse upgrade of the TFTR prototype neutral beam line at the Lawrence Berkeley Laboratory (LBL). The upgrade will extend the pulse length from 1-1/2 seconds to 30 seconds, increase the duty cycle to 10 percent (for more efficient use of the facility) and will accommodate a wide range of sources for various applications. It will be capable of testing sources developed by other laboratories such as Oak Ridge National Laboratory. The facility is being operated for the first half of FY 1982 to complete TFTR work and to begin testing the Advanced Source for MFTF-B. It will then be shut down in March 1982 for 13 months to complete installation and check-out of the upgrade. The last half of FY 1983 will be devoted to long pulse (<30 second) testing of advanced sources for TFTR and MFTF-B.

Much of the testing of advanced full size and scale sources has been limited by the existing facilities capabilities. The Advanced source now being analyzed for MFTF-B is capable of operation up to 150 KeV in continuous service. The present tests are at 80 KeV (for MFTF-B) and are limited to one second pulses by the test facility. When the NBETF project is complete, testing at 80 KeV, 30 seconds will be completed and the source will be regapped to 120 KeV and tested for 30 second pulses for TFTR. The original NBETF project was based on 170.

The original NBETF project was based on 170 KeV, 65 ampere, 30 second source operation as required for FED. The FY 1982 budgets did not support completion of this aggressive an upgrade. Because of the uncertainty of the FED need, the project was broken into two phases, as listed below, with the first phase to be completed within existing budgets and on the original schedule (April 1983). The second phase can be exercised if program needs dictate. The Phase I work will support all identified needs for existing projects such as TFTR and MFTF-B.

NBETF Parameters	Phase I	Phase II
Beam energy	120 KeV	170 KeV
Beam current	65 amperes	65 amperes
Power	7.8 MW	11 MW
Pulse length	30 seconds	30 seconds
Duty cycle	10 percent	10 percent
Operating gas	H, D	H, D
Sources	LBL, ORNL, & Others	LBL, ORNL & Others

6) GYROTRON TEST FACILITY

Operating Plan

Varian Associates now has two gyrotron test facilities capable of testing 200 kW, cw gyrotrons. OFE funded Varian in FY 1980 and FY 1981 (about $600,000 total) to modify one of these facilities to meet OFE testing requirements for the 60 GHz gyrotrons. The other facility is adequate to test 28 GHz gyrotrons. OFE has no plans to modify the second facility for 60 GHz operation; however, Varian may decide to do this at its expense. The 60 GHz facility at Varian will be used during FY 1982-83 to test development gyrotrons and condition short pulse gyrotrons for PDX and Doublet-III. Facilities operations costs are not budgeted separately. Rather, expenses are charged to various customers for each gyrotron tested.

Q2.(d) Provide detailed justification and funding levels for the FY 1983 request of $9.7 million for Development and Technology capital equipment.

A

Magnetics

The Magnetics subactivity will utilize $3.5 million of the $9.7 million total capital equipment budget allocated to Development and Technology. The LCTF requires $2.6 million and the HFTF $.7 million to complete those facilities. The remaining $.2 million will be utilized to provide equipment support to other programs at the national laboratories and universities.

Plasma Engineering

Development of neutral beams and conventional radio frequency heating systems will require $3.8 million for the NBETF upgrade discussed in response to question 2.(c) and for purchase of test equipment and test facility components. The High Heat Flux activity will use $0.2 million of equipment funds for diagnostics, instrumentation and test hardware. It is estimated that a $0.4 million in FY 1983 equipment funds will be needed to complete assembly and testing of the cw gyrotron test facility by the end of FY 1983.

Fusion Reactor Materials

Of the $9.7 million capital equipment budget, $1.6 million will provide support to the Fusion Reactor Materials program. This budget covers equipment necessary to provide (1) support and upgrade of the RTNS-II facility ($0.35 million), (2) irradiation assemblies for structural and non-structural alloys ($0.7 million), (3) post-irradiation test equipment ($0.35 million), and (4) particle beams, implementation equipment, and testing equipment for the surface coatings program ($0.2 million).

Fusion Systems Engineering

FELIX will use $0.1 million of capital equipment funds to complete electromagnetics effects test stand for First Wall, Blanket and Shield engineering testing. The Tritium Systems Test Assembly will use $0.1 million for the purchase of spare parts.

No capital equipment funds are budgeted in the Environment and Safety and Fusion Energy Applications categories.

Q3(a). *Provide detailed FY 1982 and FY 1983 funding levels for each task/subtask/project carried out by the Applied Plasma Physics activity.*

A. The detailed FY 1982 and FY 1983 funding levels (B/A, 000's) for each subactivity/task/subtask carried out by the Applied Plasma Physics activity are described below:

Applied Plasma Physics Activity

Subactivity	FY 1982	FY 1983
Advanced Fusion Concepts	$ 17,300	$ 18,900
Experimental Plasma Research	15,500	17,100
Fusion Theory	21,400	22,800
National MFE Computer Network	13,200	14,500
Capital Equipment Total	6,200	4,000
Total for Activity	$ 73,600	$ 77,300

The detailed FY 1982 and FY 1983 funding levels (B/A,000's) for each task/subtask carried out by the Advanced Fusion Concepts subactivity are described below:

Advanced Fusion Concepts Subactivity Funding Levels
(Operating Dollars, B/A in 000's)

Tasks/Sub-Tasks	FY 1982	FY 1983
• Reversed Field Pinch	$ 6,155	$ 6,200
• Compact Toroid (CT) Development:		
Compact toroid Experimental (CTX) Facility	4,500	5,000
S-1 Spheromak	2,750	3,800
Paramagnetic Spheromak	300	330
Field Reversed Configuration (FRC): TRX-1	540	700
Field Reversed Configuration (FRC): Conical Θ-Pinch	160	180
Auxiliary Heating: RF & Beams	780	850
• Alternate Fuel Studies:		
Multipole Experiments	875	710
Fuel Cycle Analysis	480	520
• External Confinement Studies:		
Stellarator Experiments	250	220
System Analyses	325	390
• Undesignated	185	0
Total for Subactivity	$ 17,300	$ 18,900

The detailed FY 1982 and FY 1983 funding levels (B/A, 000's) for each task/subtask carried out by the Experimental Plasma Research subactivity are described below.

Experimental Plasma Research Funding Levels
(Operating Dollars, B/A in 000's)

Tasks/Sub-Tasks	FY 1982	FY 1983
● Plasma Heating:	$ 1897	$ 2070
Lower Hybrid Heating	956	937
Alfven Wave Heating	202	270
Electron Cyclotron Heating	389	383
Ion Cyclotron Heating	350	480
● Atomic Physics:	2298	2719
Impurity Collision Processes	1312	1540
Radiative Rates	295	349
Ion Sources & Neutral Beam Processes	691	830
● Diagnostics:	4181	4566
Far Infrared	1555	1600
Beam Probes	810	970
Laser Probes	480	405
UV Spectroscopy	289	346
X-Ray Spectroscopy	593	580
Cyclotron Harmonics	255	405
Electromagnetics	0	60
Neutron	200	200
● Plasma Properties:	3092	3300
Mirror Physics	1062	1090
Tokamak Physics	1310	1400
High Beta Research	720	810
● Superconducting Materials	560	600
● Fusion Plasma Research Facility (TEXT)	3136	3700
● Other	335	145
Total for Subactivity	$15,500	$17,100

The detailed FY 1982 and FY 1983 funding levels (B/A, 000's) for each task/subtask carried out by the Fusion Theory subactivity are described below:

Fusion Theory Subactivity Funding Levels
(Dollars, B/A in 000's)

Tasks/Sub-Tasks	FY 1982	FY 1983
Tokamak Theory	$ 8,746	$ 9,333
Portions Located at Major Sites	$ 6,588	$ 7,140
1. General Atomic Company	$ 1,400	$ 1,520
2. Massachusetts Institute of Technology	553	610
3. Oak Ridge National Laboratory	1,865	2,015
4. Princeton Plasma Physics Laboratory	2,770	2,995
Mirror Theory	$ 5,071	$ 5,440
Portions Located at Major Sites	$ 2,720	$ 2,720
Lawrence Livermore Laboratory	$ 2,720	$ 2,940
Alternate Concept Theory	$ 5,185	$ 5,685
Portions Located at Major Sites	$ 3,120	$ 3,372
1. Los Alamos National Laboratory	$ 1,790	$ 1,930
2. Oak Ridge National Laboratory	1,120	1,215
3. Princeton Plasma Physics Laboratory	210	227
Generic Theory	$ 2,398	$ 2,342
Portions Located at Major Sites	$ 165	$ 179
1. Los Alamos National Laboratory	$ 110	$ 119
2. Oak Ridge National Laboratory	55	60
Total for Subactivity	$21,400	$22,800

Fusion Plasma Theory Project

	FY 1982		FY 1983	
	B/A	B/O	B/A	B/O
Argonne National Laboratory	$ 78	$ 78	$ 81	$ 79
Arizona, University of	66	66	72	72
Auburn University	80	80	86	86
California Institute of Technology	65	65	70	70
California University of Berkeley	149	149	148	148
California University of Los Angeles	776	776	798	798
California University of San Diego	50	50	0	0
Columbia University	168	168	180	180
Connecticut, University of	65	65	70	70
Cornell University	180	180	220	220
Dartmouth College	27	27	0	0
General Atomic Company	1,400	1,374	1,520	1,476
Georgia Institute of Technology	25	25	25	25
Iowa, University of	10	10	0	0
Jaycor	60	60	0	0
La Jolla Institute	60	60	65	65
Lawrence Berkeley Laboratory	238	233	257	249
Lawrence Livermore National Laboratory	3,255	3,193	3,520	3,417
Los Alamos National Laboratory	2,010	1,971	2,049	1,990
Maryland, University of	350	350	380	380
Massachusetts Institute of Technology	1,110	1,110	1,206	1,170
Mathematical Sciences Northwest	50	50	60	60
Michigan, University of	50	50	50	50
Missouri, University of	50	50	0	0
National Bureau of Standards	57	57	62	62
Naval Research Laboratory	120	120	45	45
New York University	1,060	1,041	1,112	1,079
Northwestern University	50	50	55	55
Oak Ridge National Laboratory	3,040	2,984	3,290	3,194
Pennsylvania State University	55	55	60	60
Princeton Plasma Physics Laboratory	2,980	2,923	3,222	3,128
Rochester, University of	50	50	50	50
Science Applications, Inc.	750	750	800	800
SRI International	30	30	86	86
Stanford Leland Jr University	60	60	30	30
Texas, University of	800	785	865	840
Texas, University of (Institute for Fusion Studies)	850	850	1,000	1,000
TRW, Inc.	50	50	0	0
Undesignated	621	600	773	773
William and Mary, College of	75	75	81	81
Wisconsin, University of	256	256	302	302
Wisconsin, University of	25	25	0	0
Yale University	102	102	110	110
Total, Fusion Plasma Theory	$21,403	$21,103	$22,800	$22,300

The detailed FY 1982 and FY 1983 funding levels (B/A,000's) for each task/subtask carried out by the National MFE Computer Network are described below:

Tasks/Subtasks	FY 1982	FY 1983
● National MFE Computer Center	$ 11,450	$ 12,675
Manpower	5,255	5,950
Lease-Class VI	3,346	3,346
Maintenance	1,361	1,597
Communications	728	800
Supplies and Services	760	982
● User Service Centers	1,750	1,825
Total for Subactivity	$ 13,200	$ 14,500

3.(b) *Provide detailed FY 1982 and FY 1983 funding levels and justification for each of the small special purpose experiments funded by OFE's Applied Plasma Physics activity, including 1) Versator, 2) Microtor, 3) Macrotor, 4) Tokapole, 5) TERP, 6) TORUS-II, 7) TEXT, 8) PRETEXT, 9) ACT, 10) LAMEX, 11) UC/Irvine Mirror Device, 12) Constance, 13) ZT-40, 14) FRX-C, 15) S-1 Spheromak, 16) Surmac, 17) Octupole, 18) Stellarator, 19) TRX-1, and 20) all other appropriate experiments. Identify funding by experimental device and by facility and/or institution.*

A. Part I. Experimental Plasma Research Subactivity Devices: Funding and Justification

1. Introduction

The work done on the small special purpose experiments described in detail below, taken together, forms the Plasma Heating and Plasma Properties tasks of the Experimental Plasma Research subactivity. The devices are grouped by subtasks.

These experiments are relatively inexpensive, and attack fundamental advanced and exploratory problems. They have often provided the first indications of productive lines of research which have been subsequently confirmed and studied in detail on the larger, more expensive experiments. In this manner they have been extremely cost-effective in advancing the state of knowledge in fusion energy.

2. Lower Hybrid Heating

Versator - MIT

Versator II provides a tokamak plasma suitable for testing lower hybrid current drive (LHCD) RF heating in the lower hybrid range of frequencies (LHH), and heating at the electron cyclotron frequency (ECH). Successful RF heating and current drive have been demonstrated in some ranges of density, plasma current toroidal field and impurity concentration. Pioneering work on the combined effects of LHH and ECH is now in progress. The results have special significance because they may point the way toward steady-state tokamak operation.

	FY 1982	FY 1983
Operating	$ 675,000	$ 650,000

ACT I - PPPL

ACT I is a steady-state toroidal device without inductively produced plasma current and the resultant rotational transform. It has been used for experiments on wave propagation heating and current generation, and the first observations of successful RF current drive were made on this machine. More recently, it is being used to study the excitation and mode conversion of ion-Bernstein waves as an improved version of RF heating.

	FY 1982	FY 1983
Operating	$ 450,000	$ 450,000

3. Alfven Wave Heating

PRETEXT, University of Texas

The PRETEXT experiment was initiated several years ago to study tokamak startup problems, and to provide a test bed for development of the diagnostics and other auxiliary systems for TEXT. The preparation of TEXT subsystems is now substantially finished, and the device is being used to study Alfven wave heating and current drive, and the use of driven Alfven waves as a plasma diagnostic. This work is expected to near completion during the coming year. Therefore, it is anticipated that a phase-out of PRETEXT will begin in FY 1983, and the involved personnel will devote their energies increasingly to TEXT.

	FY 1982	FY 1983
Operating	$ 202,000	$ 270,000

The Tokapole experiment at the University of Wisconsin also contributes to the Alfven Wave Heating Subtask. It is described under the Tokamak Physics Subtask.

4. ECRH Subtask

Experiments are underway on Versator by scientists at MIT and NRL to evaluate ECRH energy propagation and deposition in the plasma. Versator is described above under the LH heating subtask. Tokapole at the University of Wisconsin uses ECRH wave energy to initiate tokamak discharges and to shape radial plasma profiles.

5. ICRH Subtask

The Macrotor experiment at UCLA is partly directed at ICRH studies. The emphasis is on antenna configuration studies and plasma transport during heating. The Macrotor program is described more fully under the Tokamak Physics Subtask.

6. Tokamak Physics

Microtor, UCLA

During FY 1982, Microtor has been fitted with a hot liner and will be operated at 4T toroidal field with both ohmic and RF heating. It is the only tokamak in the United States capable of operating at elevated wall temperatures. It will be used to study the recycling of hydrogen between plasma and wall, the trapping of hydrogen isotopes within the wall, wall/limiter pumping, and the effectiveness of various wall coatings, all as a function of wall temperature. The results are particularly relevant because they provide our first simulation of the hot wall effects which will be present in fusion reactors.

	FY 1982	FY 1983
Operating	$ 460,000	$ 500,000

Macrotor - UCLA

Macrotor is devoted to studies of ion cyclotron resonant frequency (ICRF) heating, antenna configuration studies, transport studies and current drive. A successful demonstration of current drive by a relativistic electron beam (REB) was just completed and a study of radial transport due to radial electric fields, with significant implications for particle and energy confinement, is now underway.

	FY 1982	FY 1983
Operating	$ 550,000	$ 680,000

Tokapole - University of Wisconsin

Tokapole II is a four-node poloidal divertor tokamak, the only small machine of this type in the United States. It has recently been devoted to studies of low-q discharges, shear Alfven wave heating, ECRH preionization and startup, and poloidal ohmic heating. Because of its similarity to the larger PDX experiment at Princeton, it is used as a backup experiment and for comparative purposes, especially on the problem of disruptions influenced by the positioning of mechanical limiters.

	FY 1982	FY 1983
Operating	$ 450,000	$ 500,000

BIGMAK - Cal Tech

In spite of its name, BIGMAK is a small conventional tokamak devoted to the study of the causes of fluctuations in tokamaks, and the relationship between fluctuations and anomalous transport of particles and energy. Electric and magnetic field fluctuations can be studied directly and in some detail over most of the plasma volume by using simple probe techniques. By contrast, in large hot plasmas such as PLT, which would destroy probes, only indirect and chord averaged information is available. The results have enormous potential impact on the design of future tokamaks, since anomalous transport is closely related to scaling, which is not completely understood but is used in the planning of large experiments.

	FY 1982	FY 1983
Operating	$ 200,000	$ 200,000

7. Mirror Physics

LAMEX - UCLA

Experiments in the LAMEX research program are directed toward the study of key physics issues of mirror fusion in a device where detailed diagnosis is possible and the scaled plasma parameters are relevant to fusion parameter experiments. Topics of present activity are:

1. High β ($\lesssim$ 100%) MHD stability of axisymmetric, average minimum $|B|$ field configuration of the LAMEX device, including mirror mode and ballooning mode stability limits.

2. Large diameter plasma stabilization of the DCLC mode with emphasis on the scaling of stability regimes with plasma beta.

3. Characteristics and stability regions of the Alfven Ion Cyclotron (AIC) mode.

4. Mirror confinement at high electron temperature ($.1\ T_i < T_e < 2\ T_i$). ECRH heating will be used to vary the electron temperature.

5. ICRH heating to vary and sustain T_i, enhance $T_\perp$ For the study of AIC mode and create a transient sloshing ion distribution for the purpose of studying sloshing ion stability and stabilization of loss cone modes.

6. Development of an extensive set of plasma diagnostics, including both probes and nonperturbing diagnostics.

	FY 1982	FY 1983
Operating	$ 270,000	$ 300,000

UC/Irvine Mirror Device

This experiment evaluates the stabilization of a simple mirror-confined plasma against flute instabilities using surface line tying, and to adapt surface line tying to the thermal barrier concept. The surface line tying is accomplished by placing a cold plasma "blanket" around the plasma. The work is particularly significant because it is widely believed that if a simple mirror could be stabilized against flute instabilities, it would be an economically attractive alternative to the Yin-Yank coils currently used on TMX and to be used on MFTF-B.

	FY 1982	FY 1983
Operating	$ 217,000	$ 200,000

Constance II - MIT

Constance II is a minimum beta mirror device fueled by a hydrogen loaded titanium washer gun. It was designed to seek solutions for the microinstabilities driven by the ion loss-cone distribution inherent to a population of mirror confined ions. It is presently devoted to experiments on hot electron stabilization of microinstabilities, electron cyclotron heating, ion cyclotron, heating and plasma gun studies. The results are particularly significant because they shed light on the stability of sloshing ion distributions and end plugs with thermal barriers generated by groups of heated electrons, which are major issues for the national mirror program.

	FY 1982	FY 1983
Operating	$ 425,000	$ 470,000

8. High Beta Equilibrium

Torus II - Columbia University

Torus II is a short pulse tokamak without auxiliary heating, especially designed to explore a theoretically predicted region of high beta stability. The work is of appreciable significance for the tokamak program, since the experimental identification of boundaries and a high-beta (10-30%) region would open new possibilities in the design of large-scale tokamaks which now must operate with low-beta (1-5%). Over the near term, the experiment is focused on utilizing improved diagnostics to understand the MHD stability properties and basic plasma parameters of Torus II, especially as influenced by impurities.

	FY 1982	FY 1983
Operating	$ 500,000	$ 700,000

TERP - University of Maryland

TERP is an experiment to investigate equilibrium, stability and transport in a non-circular cross-section, tokamak-like high beta plasma. Measured equilibrium properties are used as the starting point for a linearized MHD initial value instability code. Code predictions for growth rates and eigenfunctions are then used to guide measurements of fluctuating magnetic fields and density perturbations in a continuing search for high beta ballooning modes, which may limit high beta tokamak operation.

	FY 1982	FY 1983
Operating	$ 220,000	$ 110,000

9. TEXT Subtask - University of Texas

The Texas Experimental Tokamak (TEXT) is a national users facility for research on fusion plasmas. It is a conventional medium-scale tokamak with excellent experimental access designed to provide for experiments that are not compatible with schedule and program commitments of the major tokamaks. It efficiently provides a plasma of moderate size and temperature for experiments by scientists from institutions throughout the country. The user experiments are scheduled around a "core" program studying anomalous electron transport, which is conducted by University of Texas staff in conjunction with outside users. An example of user experiments on TEXT is a project to test a new diagnostic technique that if successful may be applied to one or more confinement concepts.

	FY 1982	FY 1983
Operating	$ 3,136,000	$ 3,700,000

B. Part II. Advanced Fusion Concepts Subactivity Devices; Funding and Justification

1. Introduction

Consistent with the Department's policy of developing the maximum potential of fusion for commercial application, a balanced program of investigating and assessing alternate approaches with various reactor options is being pursued. The alternate concepts include a variety of physics options in addition to the mainline approaches. Thus, a balanced development of confinement physics as well as reactor options is included within the OFE development program.

The present Advanced Fusion Concepts subactivity includes major tasks in the reversed field pinch and compact toroids at several laboratories. A smaller component of activity seeks to examine the possibilities of alternate fusion fuel cycles. At present, multipole development is supported in the AFC program as a potential confinement configuration for the high temperature fusion fuel cycles (those based on proton reactions). Optimized versions of mainline approaches (advanced tokamaks and tandem mirrors) are considered candidates for confinement of the lower temperature fusion fuel cycles (those based on deuterium reactions). Finally, a seminal level of activity has been maintained for several years to evaluate the prospects of torsatron configurations and to allow a meaningful U.S. collaboration with Western Europe, Japan and the Soviet Union in this area.

In the following sections the experimental devices supported by the AFC subactivity will be introduced. This subactivity has only two concepts under intensive experimental development:

- Reversed-field-pinch approach at Los Alamos National Laboratory
- Compact toroid approach at several institutions

Supporting studies, including modest experimental effort, are directed toward:

- Alternate fusion fuel possibilities at the University of Wisconsin and UCLA
- Torsatron/Stellarator results at the University of Wisconsin

This latter activity is much too small to be able to advance development of these issues substantially, but are essential program elements allowing effective international cooperation with attendant benefit to the U.S. as mentioned above.

2. Reversed-Field-Pinch

The reversed-field-pinch (RFP), like the tokamak, is a toroidal, axisymmetric confinement device. Both systems use a combination of poloidal and toroidal magnetic fields to confine a plasma in a minimum energy state. For both systems the poloidal field is created by inducing a large toroidal plasma current. Potentially attractive RFP features include:

- Most aspects of device geometry and size can be chosen solely on the basis of engineering consideration and not by physics constraints.
- The beta limits predicted for the RFP are considerably greater than that for tokamak systems.
- The plasma may be brought to ignition by ohmic heating alone.
- The confinement of plasma with high-to-moderate beta is achieved primarily by poloidal fields, which characteristically decrease with increased distance from the plasma, thereby considerably reducing fields and stresses at the coils.

These advantages are unique to a system that derives its confinement primarily from self-generated fields.

The ZT-40 at Los Alamos National Laboratory (LANL) is the only U.S. device of this type. Additional U.S. devices would be required for adequate program development if it were not for international cooperation with the United Kingdom, Italy, and Japan, which have modest size experimental devices of the same type and the existence of international treaties to coordinate research. This precludes the need for several U.S. devices to accomplish the necessary development goals for this approach.

The near-term objectives in the RFP development have been drastically overhauled as a result of the recent rapid progress from the ZT-40 device. Original objectives have been met or exceeded by these results; new objectives have been identified. Specifically, the experimental duration and heating are at 10 milli-seconds and 350 electron-volts, respectively, both exceeding the administrative goals of the ZT-40 project.

RFP Experimental Device	FY 1982	FY 1983
ZT-40 at LANL	$ 6,155,000	$ 6,200,000

3. Compact Toroids

Compact toroidal systems (CT) are characterized by the lack of any magnetic field generating conductor that links the plasma configuration externally. It is anticipated that this substantial modification will permit maximum simplicity in the designs of blankets and shields (solenoidal or spherical). CT's are closed magnetic systems which may or may not have a toroidal field. Reactor advantages include flexible output power and significant technological simplifications. At present there are several reactor embodiments which have been studied in varying degrees of sophistication ranging from low to moderate. They utilized single or multiple cells with stationary or moving plasmas. The U.S. fusion program initiated an important and highly promising CT development program in FY 1979. This activity fills a significant gap in world-wide fusion research and one that had been previously omitted in the U.S. program. Small output-power, physically small, and technologically simplified reactor approaches have been highly recommended by utility and industrial representatives. This AFC Subactivity supported the conception of this new approach, and organized a number of earlier disparate research groups into a coordinated program. Three separate versions were identified; i.e., spheromak (toroidal field), field-reversed configuration (FRC) (no toroidal field), and "Astron"-like rings.

Methods of generation were developed, equilibria established, and gross stability demonstrated and controlled. This experimental development program is being accomplished in the U.S. for about $10 million/annum expenditure, and research is conducted on a series of highly specialized devices. The near-term objective is to identify which of these approaches offers the best potential for further development.

In the past the development pace has been limited by unresolved technical issues. Recent success, with the exception of impurity control, has led to a situation in which the next development stage is now limited by funding. This funding limitation is being dealt with by: (1) employing a series of low cost devices (mostly at universities) with specific development goals, (2) a common experimental facility (CTX at LANL) to permit side-by-side comparative measurements to identify the superior CT version, (3) a new modest sized device (S-1 at PPPL) to extend confinement parameters to necessary levels to permit reactor relevant studies, and (4) elimination of one potential configuration ("Astron"-ring) based on results from system studies.

There remains two competing versions of the Compact Toroid; these are the spheromak and the FRC. The CTX facility at LANL is commissioned to study both versions and to accomplish the comparative measurements necessary to select the superior version. The FRX-C device is the FRC source needed to generate the configuration for study in CTX. The spheromak source is an intimate part of the CTX. Equilibria, stability, variations in configurations, auxiliary heating, impurity control, and thermal transport of both versions are to be studied in the CTX facility.

The lead spheromak group is located at PPPL where the modest size S-1 device will be placed into operation in FY 1983. This device will generate plasmas of 100 cm major and 50 cm minor radius, with electron temperatures of 200 eV or greater for experimental times of several milliseconds. All performance ranges are beyond the capability of any other spheromak device presently in use.

A smaller scale prototype device, S-1/C, exists at PPPL to assist in preparations for operations with the larger device. The paramagnetic spheromak (PS-1) at the University of Maryland is a small flexible device which created the world's first laboratory spheromak at a cost of $65,000 and six months of time. It has continued to produce specialized results on alternate methods of generation, stabilization of MHD modes, variations of geometry, and alternate winding configurations.

The Maryland device will be used in FY 1982 and FY 1983 to investigate these and other issues in spheromak development, and which results will be confirmed later on the larger, more expensive S-1 at PPPL.

The lead group working on the FRC version of the CT's is Mathematical Sciences Northwest, Inc. (MSNW) of Seattle, Washington. It has a modest size device, TRX-1, which is being used to study an important alternate method of generating FRC's first discovered by a group in the Soviet Union. Slower rise-time operation, axial versus radial implosion heating, larger diameter, and multipole-stabilized, this experimental program is developing a variation of the FRC different from the FRX-C device at LANL, and one that has been examined in reactor studies sponsored by the Electric Power Research Institute (EPRI). These studies have developed a reactor version that is the most compact magnetic fusion concept presently under development.

The FRC program is also supported by one low cost, flexible project at the University of Washington, Seattle. The ability of this group to examine quickly exploratory issues with inexpensive experiments means that the larger experiment at MSNW can be reserved for studies of crucial issues. At present, research is devoted to a study of the stability of the FRC with smaller relative values of the ion gyroradius, and to studies in a dual conical theta pinch of the generation, translation, and re-fueling of compact toroids.

In addition to the studies of the two versions of the basic compact toroid geometry, single purpose studies are underway on devices that save development time and cost because of their flexible, specialized nature. Compact toroids require auxiliary heating to reach fusion ignition as do tokamaks. As in tokamaks neutral beam heating may provide one heating method, albeit expensive. Several potentially lower cost auxiliary heating options are being studied for compact toroid development and will have relevance to the mainline approaches as well. RF heating is being studied in the HBQ machine at the University of Washington. Further, charged-particle beam heating has important potential advantages over neutral beam heating. Ion beam injection into toroidal magnetic fields is under investigation in a special device at the University of California, Irvine.

IREX source development for multiple ion pulses is being jointly sponsored with the Development and Technology Division at Cornell University. Finally, the physics and applications of electron beams for compact toroid heating and stabilization is being studied in the RECE experimental device at Cornell, and the SEEBIE experiments at the U.S. Naval Research Laboratory.

CT Experimental Devices	FY 1982	FY 1983
Multiple Purpose:		
CTX facility at LANL FRX-C at LANL	$ 4,500,000	$ 5,000,000
Spheromak Version:		
S-1 at PPPL	2,140,000	2,800,000
S-1/C at PPPL	790,000	1,000,000
PS-1 at Maryland University	300,000	330,000
FRC Version:		
TRX-1 at MSNW, Seattle	540,000	700,000
FRC at Univ. of Washington	160,000	180,000
Auxiliary Heating:		
HBQ at Univ. of Washington	150,000	170,000
IBM at UC, Irvine	180,000	180,000
IREX at Cornell	75,000	100,000
RECE at Cornell	225,000	230,000
SEEBIE at NRL	150,000	170,000

4. Multipoles for Alternate Fusion Fuel Confinement

Alternate fuel cycle systems offer the greatest possibilities of minimizing the environmental impact of fusion power systems. It may be possible to reduce or eliminate tritium inventories, improve plant efficiencies to about 60% by use of direct conversion, decrease induced radioactivity, and increase first wall lifetimes. These fuel cycles require higher ion temperatures and beta values than D-T cycles. For this reason, the present main-line low beta toroidal systems will probably not be acceptable confinement systems, and others must be developed. One class of candidates consists of multipoles of various orders.

This is the only experimental program worldwide to develop this confinement approach that could employ the most desirable of all fusion fuels--neutron free cycles that promise major environmental benefits. Two multipole devices are supported, similar but with important differences: (1) The UCLA Surmac is a dodecapole (ℓ=6) device that is used to study confinement and heating of high temperature (a necessity for alternate fusion fuels) plasmas. Studies are directed toward beta limits, and neutral beam heating (different physical phenomena than in tandem mirrors and tokamaks). 1 keV ion temperatures have been achieved--a record for non-mainline (tokamak or mirror) confinement. With the addition of electron heating by rf and ohmic means during FY 1982 and FY 1983, basic ion thermal transport in reactor relevant parameter regimes can be studied. This is a major goal of any fusion confinement development program. (2) The Levitated Octupole at the University of Wisconsin is a multipole with ℓ=4, and much larger in volume than the SURMAC at UCLA. It is comparable in size to the PLT tokamak at PPPL. This size requires larger heating powers for neutral beams and auxiliary electron heating. 2 MW's of NBI and 2 MW's of rf have been acquired for this device in the past two years, and will be employed in FY 1982 and FY 1983 to study beta limits, instabilities and transport. Record beta values of about 40%, and in excess of theoretical predictions have been achieved. The understanding of this is important for alternate fusion fuel cycle development and for the beta limit studies in tokamaks.

Multipole Experimental Devices	FY 1982	FY 1983
Surmac at UCLA	$ 480,000	$ 450,000
Levitated Octupole at U. of Wisconsin	395,000	260,000

5. Stellarators

The stellarators are toroidal devices in which the magnetic coils are wound at an angle around the toroidal plasma vessel. The advantage of this arrangement is that a toroidal plasma current is not required and hence the devices can operate in steady state. One problem with the arrangement is the fabrication and support of the magnet windings. Current efforts are oriented toward design studies, theoretical work and limited experimental studies.

Two very small stellarators, Proto-Cleo and the Intermediate Modular Stellarator (IMS), are supported at the University of Wisconsin. This activity, combined with theoretical, reactor and design studies, are producing results that have led to improvements in the mainline toroidal confinement program. The ISX-C Project at ORNL supported by the Toroidal Confinement Systems Division is a direct consequence of the results obtained in these AFC Branch studies. The two small Wisconsin stellarators are primarily intended to answer important reactor design questions. Can the helical windings that are so beneficial to toroidal confinement be made modular and effective for confinement purposes? This has been studied theoretically and will be submitted to experimental verification during FY 1982 and FY 1983 by direct side-by-side measurements on two small, otherwise identical devices.

Stellarator Experimental Devices	FY 1982	FY 1983
Proto-Cleo at Univ. of Wisconsin	$ 250,000	$ 220,000
IMS at Univ. of Wisconsin		

3.(c) Provide detailed FY 1982 and FY 1983 funding levels for the Fusion Theory subactivity. Identify funding levels of the subactivity for 1) specific portions located at the sites of major programs, and 2) by facility and/or institution.

Fusion Theory Program

The fusion theory program is divided into four categories based on thematic areas. These are: tokamak theory, mirror theory, alternate concept theory, and generic theory. As the name implies, the first three categories are in support of specific magnetic geometries. The fourth category, called generic theory, encompasses research into fundamental problems of fusion plasma physics common to more than one magnetic geometry. This category also contains the development of new methods and approaches of dealing with fundamental plasma properties, as well as atomic physics theory of plasma impurities. As can be seen from the tables accompanying Question 3.(a) above, device-oriented theory is largely located at the national laboratories where the devices are located. Thus, over 75% of tokamak theory is located at General Atomic, M.I.T., ORNL and PPPL where major experimental programs are conducted. The same holds for alternate concepts. Over 80% of EBT theory is done at ORNL, where the device is located. Similar numbers are found in reverse-field-pinch theory, spheromak theory and compact toroid theory in general. An exception to this is the funding of mirror theory, where only one laboratory, Lawrence Livermore National Laboratory (LLNL), is engaged in large-scale mirror experiments. The size of the program and its closely knit nature make it necessary to maintain a significant off-site theory effort in order to ensure proper balance. A sizable off-site mirror theory effort is maintained at SAI, Boulder, $600 thousand, and smaller, high quality efforts are funded at several universities, among them--Wisconsin (where the Phaedrus experiment is located), MIT (location of Constance and planned TARA experiments), NYU's Courant Institute, and Yale University. The on-site mirror theory effort is about 55% of the total mirror theory funding. The rest of the device-oriented funding is in universities and five private companies. These provide the program with specialized, highly flexible and responsive skills in computational physics, analytical theory and interpretive approaches to plasma physics problems related to specific devices.

Generic theory, as mentioned before, deals with fundamental problems applicable to more than one confinement geometry, as well as atomic physics. The largest contractor in this category is the Institute for Fusion Studies at the University of Texas. Research at the IFS concentrates on difficult problems such as anomalous transport and on developing advanced techniques needed to understand fusion plasmas. In the area of atomic physics the following topics are studied: atomic radiative processes (University of Connecticut), high-Z impurities in tokamaks (LANL), compilation of atomic and molecular data for fusion (NBS), effect of impurities on transport in tokamaks (ORNL and NRL), studies of properties of charged ions (Penn State) and stripped ion collisions (SRI International). The last two of the topics are a part of a theory effort in characterizing and modeling ionized and neutral beams for plasma heating and space-resolved diagnostics in tokamaks and other magnetic geometries.

Tokamak Theory

The topics studied include: equilibrium, stability, transport of heat and particles, beta limits, effect of impurities including radiation losses.

Equilibrium and Stability

These studies are based on MHD and deal with the conditions under which the plasma column is in equilibrium with the confining magnetic field. Such equilibria are calculated as a part of stability studies for each of the tokamaks in the program. Each of the tokamaks has a different operating regime, including elongation and triangularity of the plasma column, presence of poloidal or bundle divertors and different temperature and density profiles due to the kind and power of auxiliary heating. Therefore, each laboratory maintains a capability in modeling equilibrium and stability of their device by means of codes appropriate to the operating regime. In addition, disruption studies are done at ORNL, computational beta limit studies are done at ORNL, PPPL and GA, while analytic beta limit studies are performed at MIT. New algorithms for calculating equilibrium and stability are developed at NYU, Georgia Tech and GA.

Transport

Each national laboratory maintains transport modeling capability since transport determines energy confinement and is important for analyzing device performance. Laboratories maintain large and up-to-date atomic physics packages with multiple stages of ionization of the most common impurities. Transport model and computational algorithms are developed at the laboratories and at NYU, University of Texas, and MIT.

The effect of impurities in the bulk of the plasma and the interaction of the main plasma with the scrape-off region are being studied at ORNL, GA, Arizona, Georgia Tech, PPPL and Wisconsin. These contractors form a task force in which the various aspects of transport are handled by different groups. Thus, kinetic models for plasma flow in the low-density scrape-off region are developed at Arizona. Divertorless impurity control (expanded boundary) is studied at GA, while flow of plasma in divertor channels is studied at PPPL. The effect of divertor ripple fields on particle losses is studied at ORNL. Georgia Tech is developing perturbational approaches to saturated tearing modes that contribute to anomalous transport. Sources and levels of impurities are studied at PPPL and divertor design is pursued at MIT.

Auxiliary Heating

Two forms of auxiliary heating are in use in tokamaks at the present time. These are neutral beams and radio frequency heating. Calculations of neutral beam deposition profiles and optimum injection angles and energies are done at all laboratories with neutral beam programs: GA, ORNL and PPPL. Radio frequency heating theory is done at Lawrence Berkeley Laboratory (LBL) (wave propagation and self-consistent plasma dynamics), MIT (lower hybrid launching structures and mode conversion), PPPL (ECRH and ICRH launching structures and wave propagation and absorption), UCLA (nonlinear effects of RF heating), Wisconsin (plasma profile changes due to RF heating under reactor conditions).

Mirror Theory

The issues of transport and MHD equilibrium and stability will occupy a major portion of the mirror-related theory in FY 1982 - FY 1983; although work on microinstabilities and ECRH heating is also in progress. The transport and MHD studies are seen as complementary in that configurations with axisymmetry tend to have good radial transport but bad MHD stability characteristics, while systems without axisymmetry which have better MHD stability properties tend to have worse transport properties. A major portion of this work is being carried out at LLNL. There is other work on this area in progress at sites such as SAI/Boulder and Cornell, which includes exploratory work on the use of ion and electron rings to stabilize axisymmetric configurations.

Detailed work on MHD stability is in progress at LLNL, SAI/Boulder, Magnetic Fusion Energy Computer Center (MFECC), and Cornell. The principal issues at the present time are: realistic 3-D equilibria; effective line tying lengths due to axisymmetric rings and quadrupole end plugs; and stability to both ballooning and low modes. In addition, work at Iowa on plasma sheaths may provide information on the proper boundary conditions at the end-plates of mirror vacuum vessels.

Detailed work on transport is in progress at LLNL, SAI/Boulder, University of Wisconsin, University of San Diego, University of Michigan. There are currently three important issues in mirror transport theory: radial neoclassical and resonant transport due to lack of axisymmetry; end losses; and electron energy transport between center cell and plug electrons.

Detailed work on microinstabilities and ECRH heating is in progress at LLNL, Yale, University of Wisconsin, UCLA, TRW, and University of Rochester. This is supported by plasma simulation programs at Berkeley and Stanford. Two major issues are the effective suppression of RF noise in tandem end plugs and selection heating of electrons in thermal barriers.

In all of the areas mentioned, the theory proceeds in three ways. First, the data from previous and ongoing experiments must be analyzed and understood. Second , the understanding the theory provides must be applied to the design of the next generation of mirror experiments. An example of this is the evaluation of TARA versus A-cell configurations in progress at LLNL which has impacted the MFTF-B design. Third, the theory must be extrapolated to evaluate its implications for reactor design and attractiveness. Examples of this are the work at SAI and Cornell on electron and ion rings to stabilize axisymmetric configurations. Because of the length of time and amount of money required to construct a major mirror experiment it is seen as important to stimulate theoretical work on a variety of paths to achieve mirror reactor operating criteria; e.g., acceptable MHD, control over radial losses, thermal barriers. Thus, Applied Plasma Physics supports work on several schemes to achieve MHD stability and control losses. In this regard, the mirror program has benefited from ideas from EBT and other advanced concepts.

Alternate Concepts Theory

The major portion of the effort is devoted to the development of predictive capabilities for EBT, RFP, Reversed Field Configurations, and Torsatron-Stellarators.

Elmo Bumpy Torus (EBT) Physics

Major part of the program is located at ORNL, where the EBT device is located. The studies include ring core stability and energy losses, equilibrium, stability and transport in the core plasma. Radial transport models have been developed (ORNL) to obtain global confinement properties of the device. Ambipolar potential profiles have been calculated. A new efficient algorithum for the calculation of EBT equilibria has been developed (SAI). The code allows calculations in arbitrarily asymmetric geometry and arbitrary beta. Effects of the hot electron distribution function and of geometry on beta limiations due to instabilities has been determined (IFS, Maryland U., and ORNL).

Reversed-Field Pinch (RFP)

The main theory effort at present is concentrated on sustainment of a configuration near the minimum magnetic energy. The dynamics of this process are under investigations. Global two-species kinetic codes have been developed to calculate the linear stability of diffuse RFP profiles. Calculations have shown that parallel electron current may drive many MHD modes unstable simultaneously. This process may provide additional channels for approaching the minimum magnetic energy state. These results may have a direct bearing on scaling considerations for RFP (LANL). MHD models of formation stages of RFP plasma have been developed and used to predict experimental results (Columbia).

Field-Reversed Configurations, including Spheromak

In spheromak, which is a special case of field-reversed configuration stability theory, though partially developed, has already been applied to explain the experiments. The $m=1$ tilting and shifting mode has been studied. It was found that the mode can be stabilized either by conducting walls or by a conductor in the shape of a figure eight. It is now believed that all large-scale ideal modes can be stabilized with a poloidal beta limit in the range of 30-60%. Work in this area is being done at PPPL (study of figure eight stabilization), LANL (wall stabilization) and Maryland University (formation stage of spheromak) and LLNL (formation of FRC by means of a Marshall gun, stability and cross-field transport simulations).

Stellatator-Torsatron

Reduced non-linear resistive MHD equations have been obtained (NYU) and are used to study equilibria in stellarators. Linear stability of $\ell=2$ stellarators is studied against $n=1,2,3$ modes. It has been shown that $\ell=2$ stellarators have good stability properties. Torsatron configurations are studied with the aim of simplifying coil geometry, minimizing magnetic forces, and obtaining high beta equilibria. Studies have been made on $\ell=4$, $\ell=2$, and a combination of the two. The effect of compensating coils capable of generating a variable vertical magnetic field was also examined (MIT). It was found that such a system provides a maximum parameter range with regard to rotational transform and shear profiles, magnetic well depth and shaping of flux surfaces.

A new effort is underway at ORNL to study design and performance of advanced toroidal confinement devices that offer flexibility of rotational transform and shear profile control and can behave either as stellarators or tokamaks, depending on the amount of current supplied to auxiliary winding designed to provide variable rotational transform.

Work at PPPL on configurations using circular toroidal field coils plus a current carrying toroidal conductor (the Heliac) has shown that this may lead to desirable simplicity of design plus high stable beta.

Generic Theory

Generic theory deals with fundamental aspects of the behavior of fusion plasmas that are independent of the confinement geometry. It also deals with important and complex problems in specific confinement geometry whose solutions are likely to require a long time span. An example of this is anomalous electron transport in tokamaks. Although empirical formulas exist to take account of the effect of anomalous electron transport on energy confinement times and scaling in present experiments, first principle models are necessary to properly understand and predict anomalous electron transport for design of future reactors. Without these, the extrapolation of empirical scaling laws beyond present experiments is uncertain.

The main center of research into fundamental problems is the Institute of Fusion Studies (IFS) at the University of Texas. The topics studied at the Institute include stochasticity in non-Hamiltonian systems, kinetic ballooning theory, drift wave turbulence and anomalous transport and non-linear phenomena in fusion plasmas. Alternate concepts are also a topic of research at IFS. Research is done on low frequency stability of the bumpy torus and stability of the tandem mirror, particularly against finite beta drift waves. Stellarator stability and beta limits are also studied.

The second category of generic theory includes the development and application of new mathematical and numerical analysis techniques to fusion problems. The topics include: development of smoothing techniques in particle simulations (LBL), development of large time step algorithms in field implicit electron transport codes (Northwestern), application of particle codes to fluid studies (UCLA), and the study of chaotic behavior of highly non-linear systems, such as MHD plasma flow (LaJolla Institute).

The third category of generic theory includes atomic and molecular physics. The work in this area is concentrated on radiation models from heavy impurities such as molybdenum, iron, chromium, nickel and titanium. Radiation from such common impurities as carbon is now well known. Radiation models make it possible to assess, for a given concentration of heavy impurities, the extent of radiation losses and how severe the resultant cooling of the plasma will be. In addition, lines of these elements are now used for temperature and impurity diagnostics. Charge exchange cross-sections for multiple charged impurity ions of oxygen, carbon, nitrogen, iron, titanium, chromium and nickel are studied. On the basis of experimental measurements, theoretical calculations provide particle losses and radiative power emitted. Spectroscopic line strengths are used to assess impurity concentrations. A second area of atomic research is the calculation of negative hydrogen ion concentrations in ion sources. These calculations provide an important input into the modeling of neutral beam design and performance.

3.(d) Provide detailed justification and funding levels for the FY 1983 request of $4.0 million for Applied Plasma Physics capital equipment.

Subactivity	FY 1983 (B/A in 000's)
Advanced Fusion Concepts	$ 1,400
Experimental Plasma Research	1,600
Theory	0
National MFE Computer Center	1,000
Total APP Equipment Funds	$ 4,000

The quipment funding request for the Advanced Fusion Concept subactivity is $1,400,000. These funds are to be used for cyropumping systems, data acquisition equipment, and additional power supplies for the CTX facility ($350,000) at LANL; for completion of an operational engineering R&D prototype of a variation of the ZT-40 electrical and power supply system, new multiple-beam infrared interferometry, and general laboratory diagnostic equipment for the ZT-40 ($350,000) at LANL; for a screen room, data acquisition equipment, multiple beam Thomson laser scattering system, laser interferometers, magnetic probes and spectroscopic instruments for the S-1 spheromak ($490,000) at PPPL; for a new quasi-static magnetic coil, and auxiliary power supplies for the TRX-1 ($120,000) at MSNW, Inc.; and general diagnostic equipment ($90,000) at several university experimental programs. The requested FY 1983 level is a decrease of $370,000 from FY-1982 funding.

The funding request for the Experimental Plasma Research subactivity is $1,600,000. These funds are to be used for lasers, detectors, vacuum equipment, mechanical structures, power supplies, and electronic signal processing equipment for approximately 30 experiments. A new ion source to generate highly ionized impurity elements for crossed beam measurements of collision cross sections is partly funded by this equipment budget. No equipment funds are requested for the TEXT project so that the total remains within the $1,600,000 level. The requested FY 1983 level is a decrease of $600,000 from FY 1982 funding.

The National MFE Computer Network provides integrated computing resources to all aspects of the magnetic fusion program. It is the largest such computer network within the Department of Energy and has one of the lowest cost per computer service units within the Government or the private sector. Large-scale scientific computers are located at the National MFE Computer Center (NMFECC) at LLNL and serves over 1700 scientists in the fusion program. Satellite links connect the NMFECC with five User Service Centers (USC's) at PPPL, ORNL, LANL, GA and LLNL. Each site has a medium-scale computer which has hardware and software compatible with each other. The USC's in addition to providing the mid-level computing also support the computing activities for major fusion devices. The capital equipment request for FY 1983 for the entire network is one million dollars. Of this total, $600,000 is for memory expansion, tape drives, and disks to enhance the USC's support of fusion data reduction; the remaining $400,000 is for the Computer Center, itself, for network inter-connections, graphics and a high speed printer-plotter which supports all of the user community. The NMFECC FY 1983 capital equipment request is one million dollars less than that of FY 1982.

Q4. (a) *What is the rationale that OFE's GPP request for ORNL includes both the MFE programmatic needs, as well as all of the Laboratory's general needs?*

A In budgeting for General Purpose Plant Projects (GPP), it is the Department's policy to assign the primary program at each multipurpose non-defense program laboratory the responsibility for budgeting for GPP requirements at each of these sites. GPP projects are miscellaneous construction items which cannot be specifically identified beforehand and whose total estimated costs do not exceed $1 million per project. Under this system, responsibility for funding non-defense GPP needs at ORNL has been assigned to the Magnetic Fusion Energy program on the basis that they have the largest program at ORNL in terms of funding. Many of the projects requested are for projects of a generic nature that have benefit to several programs, such as paving roadways or upgrading utilities. By budgeting for these projects all in one program, the task of budgeting and administering these projects is simplified. Projects usually cost in the range of a few $100,000 each.

(b) *Delineate that portion of ORNL's GPP funding request for FY 1983 which is specific to MFE programmatic needs and that portion which is not.*

A The tentative list of projects identified in the FY 1983 budget for ORNL GPP do not include any fusion projects. However, this list was intended only to give a tentative list of the types of projects which may be supported. Based on recent past experience, about 10 - 30 percent of these funds are used directly on fusion projects, while others have indirect benefits to the fusion program. We believe that when the final priorities are established for FY 1983, the fusion allocation will be similar to past experience.

(c) 1) *Provide additional detail and justification for the following GPP funding requests for FY 1982: 1) all LANL projects:*

A 1. AC Power Line Upgrade

This project upgrades an existing ac feeder power line from the Laboratory central power station to the Controlled Thermonuclear Research (CTR) Division area to supply power to Magnetic Fusion Energy (MFE), Advanced Fusion Concepts (AFC) experiments: the ZT-40 reversed-field pinch and Compact Toroid experiments. The power line upgrade involves the replacement of 3900 linear feet of three-conductor 4/0-cable with three-conductor 500 MCM, 15-kV cable in an existing conduit, installation of a 15-kV switching station, and the replacement of current transformers and associated ammeters. This upgrade will increase the existing feeder line capability from 5 MVA to 11 MVA.

The MFE Advanced Fusion Concepts experiments in CTR Division are moving from relatively short pulse experiments to longer pulse devices. The longer pulse requires additional power to sustain the longer current and magnetic field duration. The upgrade of the existing ac power line is needed to provide additional power to the ZT-40 experiment in the Reversed-Field Pinch (RFP) program and for the CTX facility in the MFE Compact Toroid (CT) program. The RFP ZT-40 experiment has produced very good results, exceeding its original goals. Plasma discharge durations of 10 ms exceed the 2 ms design value and will soon be limited by the on-site available power. The present substation power supply is being heavily used so that power is available only on a pulse basis and at a reduced level.

If this power line upgrade is not funded, it will seriously impair the capability to perform magnetic confinement experiments with significant pulse lengths and confinement times.

2. Modification of Building 155S for Tritium Systems Test Assembly (TSTA)

This project involves the modification of an existing building, 155S, for use as a staging and testing area for the Tritium System Test Assembly (TSTA) facility. Building 155S is a metal shell warehouse containing 3,600 sq. ft. adjacent to the TSTA facility. The building has heating and lighting. The interior walls have exposed asbestos-containing thermal insulation. Approximately 35% of the building area contains chemical vapor deposition equipment used in weapons (DOE and DOD) and energy programs. This equipment will have to be relocated in an adjacent building. The modification work would include: replacement and sealing of asbestor-containing thermal insulation; the addition of thermal insulation to the walls and ceilings; the covering of the exposed insulation with sheeting; the improvement of the lighting system; the installation of an electrical outlet system; and the relocation of the physical security fence so that 155S is contained within the unclassified TSTA area.

The modification of Building 155S is needed so that it can be used for the assembly, cold testing, and certification of large, complex TSTA components prior to their installation for tritium service in the TSTA facility (Building 155N). Malfunctioning components that are used in tritium service in 155N and can be decontaminated there, will also be moved to 155S for disassembly, modification and repair. If the project is not funded, large component assembly, colt test and certification, and component repair/modification will be very inconvenient for the TSTA operational program, which is committed to "develop, test, and qualify equipment for tritium service in the fusion program".

The TSTA facility will be completed in April 1982 within its TEC and on schedule. Fuel-loop operation will begin in May 1982. The funding of this requested building modification will greatly facilitate the TSTA operation and make effective use of Building 155S.

3. On-Site Facilities for Used Motor Generator Set Installation

Los Alamos' Magnetic Fusion Energy (MFE) program is presently searching for and has possibly located a Motor Generator Set (MGS) to energize power supply systems in the Advanced Fusion Concepts program and for the Development and Technology activities. The scope of this work is to provide the on-site facilities required to install the MGS, including the following: (1) concrete pad; (2) all-weather enclosure; (3) cooling tower; (4) pipes, valves, and instrumentation control; and (5) ac electrical input power.

The experimental program at LANL in MFE Advanced Fusion Concepts and in fusion engineering programs of development and technology requries inductive energy storage systems capable of storing and transferring a few hundred MJs on a relatively short time scale. The MGS will be used to charge the inductive energy storage coils on a time scale of a few seconds through dc power supplies. The large power pulse is supplied from the energy stored in the rotating components of the MGS so that voltage fluctuations in the ac power grid are eliminated. The experimental and development programs in MFE research at LANL are advancing to longer pulse times that require larger pulse powers. The MCS will initially be used to drive the dc power supplies for the Reversed Field Pinch ZT-40 experiment.

The present RFP ZT-40 experiment has produced very encouraging results, considerably exceeding its original goals. In order to increase the duration of the toroidal current drive beyond the present 10 ms (original goal was 2 ms) and to increase the magnitude of the toroidal current beyond the 600-kA design value, an MGS is needed to drive the power supply systems for the poloidal and toroidal magnetic field circuits. Preliminary reactor system studies of high current-density RFP systems indicate a very attractive compact RFP reactor. The requested MGS is urgently needed to pursue such higher current-density systems, not only to increase the current magnitude and duration in the ZT-40 experiment, but also for a possible follow-on experiment.

The proposed MGS facility will also be used to power Compact Toroid experiments, prototype programmed superconducting coils in the Tokamak Poloidal Field System program, and possibly an optimized toroidal confinement experiment. The inability to acquire the MGS facility will seriously limit the available pulse lengths for the fusion experiments and development activities at LANL.

4. Wooden Weather Enclosure

A wooden shed building is needed to provide a minimal weather enclosure for assembly and testing of superconducting coils in the Tokamak Poloidal Field System (TPFS) program. In order to minimize the effects of fringe magnetic field in the tests, the building will be wood framed and have a concrete slab floor with no ferromagnetic materials. The building will have an area of 21 ft. x 37 ft. = 777 sq. ft. and a height of 22 ft. The building is to be located south of and immediately adjacent to SM-253 in TA-3. The building must be available one year prior to installing the first coil to provide time to install the dewar, bring in the helium transfer lines, extend the 50 kA bus bar feeds, and install control and instrumentation wiring for the test facility.

The wooden shed building is needed for the assembly and testing of superconducting coils in the TPFS program, whose purpose is to develop and demonstrate the engineering feasibility for inductive/ohmic heating and equilibrium field programmed energy sources for large, next generation tokamak devices. The material of construction has been chosen to be wood because of the requirement that the fringe magnetic field of the coils not couple to nearby metal structures nor create forces between the coils and the building. Magnetic coupling induces eddy currents and creates losses attributable to the coil and will mask the very small losses internal to the coil that must be measured. Forces between the building and coil will create structural bracing problems that will compromise the mounting of the coil in the nonconducting dewar.

(c)2) *Provide additional detail and justification for the following GPP funding requests for FY 1983: 2) Gas and Electric Meters for MFE Facilities at LLNL:*

A The LLNL monthly electricity bill is determined by the peak electrical usage during any one-half hour period during the month. The entire month's electric bill is calculated as if that peak power was in continous use all month.

Therefore, if the power use of the individual experiments can be measured, it will be possible to determine which experiment has to reduce power use in order to minimize the peak power. This will make substantial savings in the LLNL electric bill, as well as allowing more equitable distribution of the utility costs between the various programs.

(c)3) *Provide additional detail and justification for the following GPP funding requests for FY 1983: 3) Crane for Building Valt at LLNL:*

A Without a crane inside the MFTF-B Vault, the only way to move heavy things inside the vault is to use the main building crane. In order to use the main building crane, some of the vault roof beams must be removed to provide access to the vault for this crane.

The 80 vault roof beams weigh approximately 60 tons each. To move these beams requires using the LLNL riggers, which are not always available on call.

As moving heavy things inside the vault will happen oftern, there would be substantial savings in both time and money to install a smaller crane inside the MFTF-B vault.

(c)4) *Provide additional detail and justification of the following GPP funding requests for FY 1982: 4) New Cryogenics Substation at LLNL:*

A LLNL is expanding the MFTF-B cryogenics plant as it is not practical or economical to get from local suppliers the quantity of cryogens needed to run MFTF-B.

The Helium plant will be doubled in size and a liquid nitrogen plant will be added to the original cryogenics plant.

To supply power to this cryogenics plant, a new 115 KV supply line must be provided.

(c)5) *Provide additional detail and justification for the following GPP funding requests for FY 1983: 5) Telephone/Communications at LLNL:*

A A special telephone system is necessary to connect Buildings 431 and 439. For safety reasons, a special system, possibly remote controlled, will be required. Direct physical connections between the two buildings must be kept to a minimum to improve the accuracy of the MFTF-B diagnostics. (Avoid ground loops)

(c)6) *Provide additional detail and justification for the following GPP funding requests for FY 1983: 6) Paving, Grading and Landscaping at LLNL:*

A Over many years, construction for buildings and utilities and normal heavy truck traffic have led to substantial deterioration of paved surfaces in the experimental areas. This deterioration is beyond what normal maintenance can repair. Also, with increased traffic in the area walks for pedestrians away from traffic areas must be constructed to improve personnel safety. Included in this project would be a small amount of landscaping in the area facing the Laboratory's major traffic route.

(c) 7) *Provide additional detail and justification for the following GPP funding requests for FY 1983: 7) TFTR Operations Support Office and Laboratory addition:*

A This project will provide space in close proximity to both CICADA and TFTR experimental areas to accommodate TFTR experimental operations staff.

TFTR operations support personnel, including CICADA staff and experimental physicists performing work on TFTR, need office and work space which is as close as possible to the experimental devices.

Experimental operations on TFTR will involve frequent trips by experimentalists and operators working between the main experimental area, CICADA control rooms, and office/work areas. Staff members will be required to remain in the vicinity of the experimental area for extended periods of time.

Site configuration, because of its exclusion area and with the TFTR control (CICADA) being remote from the deivce, has resulted in very little existing space being suitably located. Provision of additional work space close to both the TFTR access tunnel and the CICADA control room, such as requested in GPP Project 83-2, is essential for safe, effective operations.

Q5. Provide additional details regarding the building site preparation portion of the TARA Tandem Mirror Experiment.

A MIT has proposed to retrofit an existing building at MIT to house the TARA device and to provide room for the supporting experimental area, shops and power supplies. The TARA device is approximately 70 feet long and will weigh in the vicinity of 100,000 pounds. MIT will tear out a portion of the floor of the existing building, dig down eight feet, and pour a concrete floor for the specific support of the TARA device. The device will be housed essentially below the floor level of the building. Similar device-specific modifications will have to be made to the walls of the computer room to shield it from the radio frequency interference. The TARA device will use over 300 kW of continuous electrical power and will use pulsed power of many megawatts. A high volume cooling-water plant will be constructed to dissipate this heat. Additional air conditioning units will be used to protect the equipment. The TARA device, when operating, will be a strong x-ray source and shielding must be provided around the device for protection of personnel both inside and outside the building. The total TARA usable floor space will be approximately 30,000 sq. ft. in a high bay area with crane usable for assembling and repairing TARA.

In addition to the major structural changes, also included in the site preparation costs are various electrical and mechanical shops, neutral beam test rooms with shielding, room to house power supplies, an experimental control room, a vacuum shop, a loading bay with external door, plumbing and electrical systems for TARA, and safety systems such as fire protection. The total cost to the Department of Energy for site preparation is $2,300,000.

MIT will provide the building, offices, office furnishings, power connections for high voltage power to the building, and normal personnel support provisions such as rest rooms.

Q6. The FY 1980 Magnetic Fusion Program Summary Document included Tables 11-6, 11-7, and 11-8, enclosed for your reference, which provide actual FY 1978 BA, as well as BA estimates for FY 1979-80. Update these tables to include actual BA for FY 1979 and 1980, as well as estimates of BA for FY 1981, FY 1982 and FY 1983.

A. The enclosed table provides the response to question number 6.

FY 1979 - FY 1983 B/A Requests
Applied Plasma Physics Budget Activity
(Dollars in Thousands)

TITLE	FY 1979 BA ACTUAL	FY 1980 BA ACTUAL	FY 1981 BA ACTUAL	FY 1982 BA ESTIMATE	FY 1983 BA ESTIMATE
Applied Plasma Physics					
Advanced Fusion Concepts					
Research Operations	14,398	11,336	14,153	15,160	16,100
Major Device Fabrication					
Spheromak-1	0	1,000	2,342	1,960	2,800
ZT-40	0	0	0	180	0
Equipment	1,738	1,264	1,250	1,770	1,400
Total	16,136	13,600	17,745	19,070	20,300
Fusion Plasma Theory	16,511	15,341	19,471	21,400	22,800
Equipment	47	0	0	0	0
Total	16,558	15,341	19,471	21,400	22,800
Experimental Plasma Res.					
Fusion Plasma Research Facility	3,800	2,180	2,950	3,136	3,970
Other	8,511	9,562	15,439	12,364	13,130
Equipment	2,217	1,711	2,950	2,200	1,600
Total	14,528	13,453	21,339	17,700	18,700
National MFE Computer Net.					
National MFE Comp. Ctr.	8,360	9,210	9,651	11,450	12,675
User Service Center	3,109	2,506	1,794	1,750	1,825
Equipment	360	700	2,200	2,230	1,000
Total	11,829	12,416	13,645	15,430	15,500
Total Applied Plasma Physics	59,051	54,810	72,200	73,600	77,300

FY 1979 - FY 1983 B/A Requests
Confinement Systems Budget Activity
(Dollars in Thousands)

TITLE	FY 1979 BA ACTUAL	FY 1980 BA ACTUAL	FY 1981 BA ACTUAL	FY 1982 BA ESTIMATE	FY 1983 BA ESTIMATE
Confinement Systems					
Toroidal Confinement Systems					
Research Operations	37,960	46,027	51,987	50,560	58,550
Major Device Fabrication					
PDX	790	0	830	1,060	0
ISX Neutral Beams	1,000	1,000	0	0	0
ISX Bundle Divertor	500	1,400	500	0	0
PLT	1,100	500	0	0	0
Alcator	2,750	2,500	0	0	0
ISX ECH	400	600	0	0	0
Doublet III Vacuum Vessel	0	200	230	0	5,000
Doublet III ECRH	0	300	690	2,180	2,150
ATF-1	0	0	0	0	3,000
Equipment	7,816	7,605	6,950	6,580	7,600
Tokamak Fusion Test Reactor					
Diagnostics	2,500	5,750	4,940	8,200	13,000
Experimental Research	1,250	1,700	2,625	3,000	13,200
CICADA	0	0	3,060	4,200	7,000
Facility Operations	0	0	0	20,570	23,300
Technical Support	0	0	0	0	12,500
Equipment	1,100	3,170	4,350	6,420	8,000
Construction					
Doublet III Neutral Beams	11,397	2,500	0	0	0
PDX Neutral Beams	5,606	1,700	0	0	0
ISX-C	0	0	4,500	0	0
Total Toroidal Confinement Systems	74,169	74,952	80,662	102,770	153,300

FY 1979 - FY 1983 B/A Requests
Confinement Systems Budget Activity
(Dollars in Thousands)

TITLE	FY 1979 BA ACTUAL	FY 1980 BA ACTUAL	FY 1981 BA ACTUAL	FY 1982 BA ESTIMATE	FY 1983 BA ESTIMATE
Confinement Systems					
Magnetic Mirror Systems					
Research Operations	17,075	23,881	14,150	26,387	32,700
Major Device Fabrication					
TMX-U	650	400	10,000	913	0
TARA	0	0	250	3,400	6,600
Equipment	3,619	4,350	6,400	5,210	6,200
Mirror Fusion Test Facility Development	1,400	0	1,000	0	0
Elmo Bumpy Torus (EBT-P)					
Operating	1,600	2,355	2,000	4,000	4,000
Construction	0	2,000	5,400	13,446	0
Total Magnetic Mirror Systems	24,344	32,986	39,200	53,356	49,500
Total Confinement Systems	98,513	107,938	119,862	156,126	202,800

FY 1979 - FY 1983 B/A Requests
Development and Technology Budget Activity
(Dollars in Thousands)

	FY 1979 BA ACTUAL	FY 1980 BA ACTUAL	FY 1981 BA ACTUAL	FY 1982 BA ESTIMATE	FY 1983 BA ESTIMATE
Development & Technology					
Magnetic Systems					
Energy Storage, Transfer and Switching	1,572	825	1,900	1,500	1,000
Large Coil Program					
Coil Industrial Contract	5,700	6,320	5,450	6,400	4,000
ORNL Management	250	360	275	200	150
High Field Conductor & Magnet Technology					
Conductor Development	1,800	1,616	2,257	1,200	2,400
12 Tesla Small Coil Pro.	1,370	1,360	1,179	690	1,100
Supporting Technology	570	804	800	925	1,000
Equipment	425	940	750	1,720	900
Large Coil Test Facility					
Operating	1,450	1,475	1,546	4,100	7,050
Equipment	1,900	0	1,830	3,400	2,600
Construction	6,654	2,000	6,500	6,000	0
Total	21,691	15,700	22,487	26,135	20,200
Plasma Engineering					
Neutral Beam Systems					
Test Facility Projects	400	200	1,400	0	0
Positive Ion Beams	5,150	2,365	6,030	3,717	3,550
Negative Ion Beams	1,700	1,500	1,500	1,403	2,400
Test Facility Operations	4,003	3,060	3,935	4,400	4,845
RE Heating Systems	950	3,955	4,835	5,070	6,855
Plasma Energy Direct Recovery Systems	100	145	0	0	0
Vacuum & Particle Coll. Sys.	575	400	800	920	1,450
Plasma Fueling Systems	605	420	500	550	600
Equipment	1,739	1,660	2,250	4,390	4,400
Total	15,222	13,705	21,250	20,450	24,100

	FY 1979 BA ACTUAL	FY 1980 BA ACTUAL	FY 1981 BA ACTUAL	FY 1982 BA ESTIMATE	FY1983 BA ESTIMATE
Development & Tech. (cont'd)					
Fusion Reactor Materials					
Alloy Dev. for Irradiation Performance	2,275	2,966	4,407	4,245	5,100
Plasma Matls. Inter.	2,287	2,839	2,870	3,825	3,105
Special Pur. Matls. Dev.	545	440	840	1,070	1,395
Dam. Analysis & Fund. Studies	1,973	2,175	2,148	2,030	2,350
Rad. Fac. Dev. & Oper.					
Rad. Fac. Development	65	0	0	0	0
Rad. Fac. Operation	1,750	1,793	1,750	3,590	3,650
Fuels Fab. - OBR	250	200	150	0	0
Analysis & Evaluation	0	0	0	0	100
Equipment	1,989	1,850	1,930	1,840	1,600
	11,134	12,263	14,095	16,600	17,300
Fusion Systems Engineering					
Conceptual Design & Eng.	2,380	1,114	1,390	380	5,350
Feasibility Assessment	2,428	3,118	3,318	3,730	4,690
Blanket & Shield Eng.	1,790	928	2,127	3,460	3,750
Tritium Processing & Control					
Tritium Processing Base Program	395	578	187	150	120
Tritium Systems Test Assembly	2,600	2,000	2,850	2,700	2,490
Plasma Systems	460	310	650	450	400
Plant Systems	410	0	200	250	300
Equipment	1,080	1,080	1,540	1,210	200
Total	11,543	9,128	12,262	12,330	17,300
Environment & Safety					
Environment Assessment	345	681	986	1,250	1,000
Reactor Safety Research	630	935	1,100	1,545	1,900
Equipment	100	100	100	100	0
Total	1,075	1,716	2,186	2,895	2,900

	FY 1979 BA ACTUAL	FY 1980 BA ACTUAL	FY 1981 BA ACTUAL	FY 1982 BA ESTIMATE	FY 1983 BA ESTIMATE
Development & Tech. (cont'd)					
Fusion Energy Applications					
Synthetic Fuels	877	1,000	1,000	1,130	1,200
Fusion-Fission Hybrids	1,550	818	700	770	1,000
Emergent Applications	50	0	0	0	0
Equipment	10	120	0	40	0
Total	2,487	1,938	1,700	1,940	2,200
Total Development & Technology	63,152	54,450	73,980	80,350	84,000

FY 1979 - FY 1983 B/A Requests
Planning and Projects Budget Activity
(Dollars in Thousands)

TITLE	FY 1979 B/A ACTUAL	FY 1980 B/A ACTUAL	FY 1981 B/A ACTUAL	FY 1982 B/A ESTIMATE	FY 1983 B/A ESTIMATE
Planning and Projects					
Tokamak Fusion Test Reactor					
Development	20,144	11,285	657	1,530	0
Facility Operations	2,100	6,870	11,368	0	0
Tokamak Flexibility Operations	2,510	5,217	10,325	15,450	20,000
Equipment	710	1,600	750	1,630	0
Construction	42,000	35,000	30,000	40,100	0
Total	67,464	59,972	53,100	58,710	20,000
Fusion Materials Irradiation Test Facility					
Development	7,000	10,490	7,950	2,000	0
Equipment	750	650	650	0	0
Construction	6,900	10,000	22,600	14,000	0
Total	14,650	21,140	31,200	16,000	0
Intense Neutron Source Development	0	- 1,000	0	0	0
Mirror Fusion Test Facility					
Development	1,800	3,518	1,100	3,000	1,600
Auxiliary Component Dev.	2,070	5,506	1,000	3,930	3,400
Facility Preparation	400	2,666	2,100	220	1,000
Construction	40,000	28,200	25,000	39,858	40,000
Total	44,270	39,890	29,200	47,008	46,000
General Purpose Equipment	1,600	3,000	3,000	3,260	4,000
General Plant Projects	4,030	4,000	4,400	5,700	6,000
Total - Planning and Projects	132,014	127,002	120,900	130,678	76,000

FY 1979 - FY 1983 B/A Requests
Center for Magnetic Fusion Energy
(Dollars in Thousands)

TITLE	FY 1979 B/A ACTUAL	FY 1980 B/A ACTUAL	FY 1981 B/A ACTUAL	FY 1982 B/A ESTIMATE	FY 1983 B/A ESTIMATE
Center for Magnetic Fusion Energy					
Design Effort	0	3,300	3,520	9,150	0
Total - CMFE	0	3,300	3,520	9,150	0

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April 12, 1982

Dr. Alvin Trivelpiece
Director, Office of Energy Research
U.S. Department of Energy
Washington, D.C. 20585

Dear Dr~~. Trivelpiece~~: Al

Thank you for the testimony presented by you and Dr. Clarke on the Department of Energy's Magnetic Fusion Energy Program at the Subcommittee's FY 1983 budget review hearing on March 23, 1982. Chairman Bouquard and Congressman Hollenbeck would like to supplement the record of the hearing with some additional questions that the Subcommittee has regarding the program.

Dr. Clarke indicated in his testimony that he would be happy to submit for the record a complete listing of the U.S. international cooperative efforts in fusion. We would appreciate such a listing. We also request that the Department provide the Subcommittee with the following: 1) full and complete sets of the U.S. Department of Energy Field Task Proposal/Agreement forms (Schedule 189) and Construction Data Sheets (Schedule 44) for the Magnetic Fusion Energy Program for fiscal years 1981, 1982, and 1983; 2) one copy of the draft of the document titled "Large Coil Task Test Program;" and 3) one copy of the Fusion Engineering Development Plan. We appreciate your cooperation on this matter and we hope that this information can be provided by April 30, 1982.

Finally, we request that Dr. Harlan Watson, the Subcommittee's Technical Consultant on fusion, receive one copy of each report and publication which is wholly or partially funded by the Office of Fusion Energy or its contractors, as well as OFE newsletters, press releases, and program review announcements commencing from the beginning of fiscal year 1982.

If you have any general questions regarding these requests, please contact me at 225-8056. If you have any questions regarding the specifics, please contact Dr. Harlan Watson of the Subcommittee staff at 225-3472.

Sincerely,

Jack
JOHN V. DUGAN, JR.
Staff Director
Subcommittee on Energy Research
and Production

JVD:Wma
Enclosure

QUESTIONS
HEARING ON MAGNETIC FUSION ENERGY, MARCH 23, 1982

SUBCOMMITTEE ON ENERGY RESEARCH AND PRODUCTION

1. Dr. Clarke, in your testimony you stated that the Office of Fusion Energy spends approximately $186 million a year in industry.

   a) Were you referring to FY 1982 expenditures?

   b) Please document OFE's expenditures in industry for FY 1981 and FY 1982, as well as plans for FY 1983.

2. Dr. Clarke, during your testimony you stated:

   "In a flat-budget situation, the only thing that we can do to involve industry more directly or more heavily is to increase the quality of their participation rather than the quantity.

   As I emphasized, the major portion of the scientific program is in the National Laboratories, and it must remain in the National Laboratories until we reach the point at which we know which is the appropriate fusion system to be developed. We are not at that point yet."

   a) What do you mean by the term "increasing the quality of their participation?"

   b) Why is it assumed that the National Laboratories know best which is the appropriate fusion system to be developed, when the Labs will not be neither the supplier nor the user of commercial fusion systems? What assurance do we have that the Labs will not develop a device that no one wants?

3. Dr. Clarke, on page 2 of your prepared testimony you state:

   "it is not the Department's policy to take the shortest, most expedient route fusion power production if that path leads to only another source of electricity."

   a) What would be "the shortest, most expedient route to fusion power production?"

   b) What would be wrong in developing another source of electricity if it was indeed economically competitive and environmentally sound?

4. How has the British Atomic Agency Authority's decision to cancel the Reversed Field Experiment (RFX) facility impacted DOE's reversed-field-pinch program being conducted at Los Alamos National Laboratory?

5. Dr. Clarke, on page 33 of your testimony you state that the funding for the Center for Magnetic Fusion Energy has been reduced to a level at which a separate budget element is not justified.

   a) What level of funding would be considered justifiable for such a line item to appear?

   b) Why is the Center for Magnetic Fusion Energy activity subsumed in the Fusion Systems Engineering category of the Development and Technology subprogram, rather than being broken out in a separate category of funding as are Environment and Safety and Fusion Energy Applications categories which are funded at much lower levels than the CMFE efforts?

6. The FY 1983 budget request includes $5 million for the modification of Doublet III vacuum vessel. To what extent does this project depend upon negotiation of an extension of the present U.S./Japan agreement, and to what extent might the results to be obtained from the modified device be preempted by results expected from the JET (Joint European Torus) device?

7. Dr. Clarke, on page 11 of your testimony you state that the program's engineering effort assumes "that fusion engineering systems are, in large part, generic to more than one fusion approach." If this is indeed the case, then why does the Office of Fusion Energy maintain large and expensive projects in its Development and Technology subprogram? Why can't engineering development proceed as we construct and utilize our experimental research devices? Is it really necessary to maintain the numerous test stands as the program does?

8. Dr. Trivelpiece, you say that the strategy of the program is to lay the groundwork for a rational assessment of fusion's potential as a practical energy source. How do the decisions to delay MFTF-B, EBT-P and FMIT help lay the groundwork for such a rational assessment of fusion's potential?

9. The Office of Fusion Energy is about to initiate operations in the Tritium Systems Test Assembly.

a) Since we have handled significant quantities of tritium in the weapons program for years, why couldn't this knowledge be transferred in toto to the fusion program?

b) If it indeed is felt necessary to have operating experience on a working fusion device, why couldn't that experience be obtained during the operating of TFTR?

10. After TFTR has fulfilled its mission of demonstrating scientific feasibility, What does DOE and the Office of Fusion Energy intend to do with this large facility?

11. What are the detailed FY 1981, FY 1982 and FY 1983 objectives, funding levels, and program milestones for each of the budget elements of OFE's Fusion Reactor Materials subactivity, including 1) Alloy Development for Irradiation Performance, 2) Plasma Materials Interactions, 3) Special Purpose Materials Development, 4) Damage Analysis and Fundamental Studies, 5) Radiation Facilities Development and Operation, and 6) Analysis and Evaluation?

12. What are the detailed FY 1981, FY 1982 and FY 1983 objectives, funding levels, and program milestones for each of the budget elements of OFE's Fusion Systems Engineering subactivity, including 1) Conceptual Design & Engineering, 2)

Feasibility Assessment, 3) Blanket and Shield Engineering, 4) Tritium Processing and Control, 5) Plasma Systems, and 6) Plant Systems?

13. Dr. Trivelpiece, your March 22, 1982 response to the Subcommittee's request for detailed funding profiles for each of OFE's major budget activities for FY 1979 - FY 1983, provided us with actual and estimated BAs down to the individual budget element or task/subtask level. For each of FY 1982 and FY 1983, please provide a detailed funding profile of the performers of each of these budget elements.

14. What is the present capability of OFE to adequately te and evaluate candidate first wall and blanket materials in a realistic fusion reactor environment? Please identify facilities currently used (e.g., RTNS-II, HIFA, ORR, etc.), as well as models which given one confidence that one can extrapolate current work to reactor-like conditions.

15. What is the current status and how much has been expended to date, by fiscal year, on the EBT-P device and the FMIT facility?

16. a) Dr. Trivelpiece, are you familiar with the INESCO Corporation, the people who are privately developing a small fusion reactor?
    b) Is INESCO a technically credible company?
    c) How does their program relate to DOE fusion programs?

17. Are there any synergisms between the DOE and INESCO programs which can help advance the generic U.S. fusion effort?

18. If INESCO is successful in 5 years as they claim, what impacts will this have on the DOE program? Can the U.S. profit from their success?

19. What is the DOE policy concerning the transition of research data to the private sector?

20. It has been said that the goal of the Magnetic Fusion Energy Program should not be to achieve the "highest potential" of fusion for this pursuit is likely to lead to an extended and needless development of excessive R&D components, systems, and test facilities, without effective relationship to the more goal-oriented projects. Rather, the goal should be to produce fusion-generated electricity which is safe, reliable, environmentally compatible, and, hopefully, economically competitive--a worthwhile goal clearly related to our national interest and needs.

a) Please comment on this statement.

b) How does OFE ensure that, given such a broad goal as assessing fusion's highest potential, the program is being properly focused?

21. Dr. Clarke, in a letter dated March 11, 1982, Under Secretary Fiske informed the Subcommittee that Magnetic Fusion Energy FY 1982 funds totaling $2,573,000 were being deferred, including $642,000 in Applied Plasma Physics, $743,000 in Confinement Systems, $819,000 in Development and Technology, and $115,000 in Planning and Projects. Please provide the Subcommittee with the detailed breakdowns of the program elements which absorbed these deferrals, as well as a breakdown of the performers affected.

QUESTIONS SUBMITTED BY CONGRESSMAN HAROLD C. HOLLENBECK

1. Will TFTR be supported with adequate operating funds in FY 1983 and 1984 so that the schedule can be maintained for demonstrating break-even capabilities in 1985?

2. Will DOE continue to support a sufficiently broad and vigorous program so as to exploit the success of the tokamak in reaching the reactor regime?

3. Will the high productivity of the PLT/PDX research complex at Princeton be maintained?

4. Could the intent of the Magnetic Fusion Energy Engineering Act of 1980 begin to be fulfilled during this decade by utilizing the TFTR facility as a test bed for fusion engineering?

5. a) What is the Department doing to encourage constructive innovation?
   b) Please describe new directions and recent discoveries.
   c) Are we searching hard enough so that we can be reasonably sure of identifying the best route to fusion power?

6. In light of DOE proposals, can the United States maintain its leadership of the international fusion program?

Department of Energy
Washington, D.C. 20585

April 28, 1982

Honorable Marilyn Lloyd Bouquard
Chairman, Subcommittee on Energy
Research and Production
House of Representatives
Washington, D.C. 20515

Dear Chairman Bouquard:

Following the March 23, 1982, hearing on magnetic fusion energy, before the House Science and Technology Subcommittee on Energy Research and Production, you submitted questions to Dr. Alvin Trivelpiece to supplement the record. Enclosed are answers to the questions you submitted.

Copies of the responses have been sent to Dr. Harlan Watson of the Subcommittee staff.

If you have any questions, please call Ingrid Nelson or Tom Pretorius of my staff on 252-4277. They will be happy to assist you.

Sincerely,

Thomas H Pretorius

for Robert G. Rabben
Assistant General Counsel
for Legislation

Enclosures

cc: Dr. Harlan Watson
Subcommittee Staff on Energy
Research and Production

QUESTIONS SUBMITTED FOLLOWING

the

MARCH 23, 1982 HEARING

before the

COMMITTEE ON SCIENCE AND TECHNOLOGY
SUBCOMMITTEE ON ENERGY RESEARCH AND PRODUCTION

MAGNETIC FUSION PROGRAM
DEPARTMENT OF ENERGY

1. Mrs. Bouquard: Dr. Clarke, in your testimony you stated that the Office of Fusion Energy spends approximately $186 million a year in industry. Were you referring to FY 1982 expenditures? Please document OFE's expenditures in industry for FY 1981 and FY 1982, as well as plans for FY 1983.

Dr. Clarke: The amount of $186 million was an earlier estimate developed for FY 1982 based on an extrapolation of the FY 1981 level. While our accounting system does not provide specific information on all the subcontracts funded with industry indirectly through the labs, we have made an estimate of the total dollars provided by fusion to private industry. On the basis of our most recent and more complete analysis, the estimate for FY 1981 has been raised to $193.8 million, and about $229.1 million in FY 1982. We anticipate about the same proportion of the total to be allocated to provide industry in FY 1983, or about $222.0 million.

2. Mrs. Bouquard: Dr. Clarke, during your testimony you stated, "In a flat-budget situation, the only thing that we can do to involve industry more directly or more heavily is to increase the quality of their participation rather than the quantity.

As I emphasized, the major portion of the scientific program is in the National Laboratories, and it must remain in the National Laboratories until we reach the point at which we know which is the appropriate fusion system to be developed. We are not at that point yet."

2.a What do you mean by the term "increasing the quality of their participation?"

Dr. Clarke: As I indicated in my testimony, the fusion program spends nearly $200 million a year in industry. The question is not industrial participation, per se, but one of the type of industrial participation. By increasing the quality of industrial participation, I mean, working out methods to take more advantage of industrial experience in organizing and planning high technology development programs as suggested in the Magnetic Fusion Energy Engineering Act of 1980. As an example, I would like to point to the Fusion Engineering Design Center in Oak Ridge. It is almost fully staffed by experienced industrial engineers who are applying their practical experience producing a realistic engineering design and systems analysis of the next major facility in the fusion program. This participation, which is already a significantly more effective arrangement than in the past, will be increased in quality by even further involvement of senior corporate engineers in the review process.

2.b. Mrs. Bouquard: Why is it assumed that the National Laboratories know best which is the appropriate fusion system to be developed, when the Labs will be neither the supplier nor the user of commercial fusion systems? What assurance do we have that the Labs will not develop a device that no one wants?

Dr. Clarke: I do not assume and my testimony was not meant to imply that the National laboratories know best which is the appropriate fusion system to be developed. The purpose of the Department's Magnetic Fusion program is to provide industry with the basic information from which such a choice could be made. The fusion program is in the stage of defining a product, not developing a particular device. Product definition in a highly technical program such as fusion must involve the skills of both laboratories and industry to assure the product once defined will be worth developing, and I believe we are making good progress toward this goal through joint laboratory-industrial systems studies.

3.a. Mrs. Bouquard: Dr. Clarke, on page 2 of your prepared testimony you state: "It is not the Department's policy to take the shortest, most expedient route fusion power production if that path leads to only another source of electricity." What would be "the shortest, most expedient route to fusion power production?"

Dr. Clarke: The shortest, most expedient route to fusion power production would be to concentrate all of our energies on the most advanced scientific concept—the simple, pulsed tokamak. Studies such as those completed by the International Atomic Energy Agency INTOR project, and our own Technical Management Board Fusion Engineering Device (FED) Design have shown that such a device should be able to produce copious amounts of fusion power, and in the case of the INTOR device, even electricity. However, it is also true that these studies have uncovered a number of directions based on scientific and engineering technology progress, which could lead to improved performance and cost reductions not only of these first pioneering fusion systems, but of the practical power systems which might be developed from them. The Department's program is aimed at developing these improved concepts which have a much better chance of being economically acceptable.

3.b. Mrs. Bouquard: What would be wrong in developing another source of electricity if it was indeed economically competitive and environmentally sound?

Nothing whatsoever. That is one of the principal goals of our program. My statement was intended to emphasize the point that if not developed judiciously, fusion could be developed into a source of electricity that didn't meet these criteria. I believe we need to follow up on our present scientific and technological advances to define a desirable product for the fusion program which will be worth the cost of development to a practical source of electricity.

4. Mrs. Bouquard. How has the British Agency Authority's decision to cancel the Reversed Field Experiment (RFX) facility impacted DOE's reversed-field-pinch program being conducted at Los Alamos National Laboratory?

Dr. Clarke. The British decision to cancel the Reversed Field Experiment (RFX) has had serious negative consequences to the worldwide development of this fusion approach and to the U.S. program, principally located at LANL. Two years of cooperative planning have been lost and this delay will be felt on any proposed substitute such as the ZT-40 Upgrade at LANL.

5.a. Mrs. Bouquard: Dr. Clarke, on page 33 of your testimony you state that the funding for the Center for Magnetic Fusion Energy has been reduced to a level at which a separate budget element is not justified. Could you tell me what level of funding would be considered justifiable for such a line item to appear?

Dr. Clarke: We believe that it would be inappropriate to establish a budget line item solely based on the criteria of some arbitrary budget amount. There are many factors, including current budget, long-term intent, best aggregation for management, etc., which must be considered in establishing a line item.

5.b. Mrs. Bouquard: Why is the Center for Magnetic Fusion Energy activity subsumed in the Fusion Systems Engineering category of the Developmant and Technology subprogram, rather than being broken out in a separate category of funding as are Environment and Safety and Fusion Energy Applications categories which are funded at much lower levels than the CMFE efforts?

Dr. Clarke: The activities previously included within the CMFE category were subsumed within the Fusion Systems Engineering category of the Development and Technology subprogram simply as a matter of convenience. We are now considering establishing a distinct line item within the Development and Technology subprogram to satisfy the need for greater management visibility. This action could come as an individual action or as a part of a general consideration of organizational arrangements in the fusion program budget, reporting and management structure.

6. Mrs. Bouquard. The FY 1983 budget request includes $5 million for the modification of Doublet III vacuum vessel. To what extent does this project depend upon negotiation of an extension of the present U.S./Japan agreement, and to what extent might the results to be obtained from the modified device be preempted by results expected from the JET (Joint European Torus) device?

Dr. Clarke. The modification of the Doublet III vacuum vessel depends on the agreement of the Japanese for the use of upgrade equipment purchased during the present five-year cooperation. The simplest way to formalize this agreement is through an extension of the present five-year U.S./Japan agreement. The pace at which we carry out the modification depends upon the Japanese agreeing to share in the hardware cost. This is under negotiation.

Although the shapes and magnetic fields of JET and the modified Doublet III are similar, their programmatic roles are quite different and, therefore, there is little overlap expected. JET is a larger physics-oriented device with tritium and remote handling capabilities while the modified Doublet III is to be a plasma-engineering-oriented hydrogen device capable of testing FED components and advanced tokamak hardware.

7. Mrs. Bouquard. On Page 11 of your testimony, you state that the program's engineering effort assumes "that fusion engineering systems are, in large part, generic to more than one fusion approach." If this is indeed the case, then why does the Office of Fusion Energy maintain large and expensive projects in its Development and Technology subprogram? Why can't engineering development proceed as we construct and utilize our experimental research devices? Is it really necessary to maintain the numerous test stands as the program does?

Dr. Clarke. Development and Technology supports a number of large projects for two major reasons: (1) Development of the technology and engineering capability to meet experimental research device schedules requires work well in advance of its application date, i.e., usually before the initiation of those research device projects and (2) development of technology requires testing in a range that pushes the limits of performance to failure possibilities, a risk that is not normally accepted by directors of experimental facilities that focus on plasma physics. The main hardware projects carried out in the Development and Technology subprogram are the Large Coil Program, Tritium Systems Test Assembly, Plasma Heating Test Facilities (both neutral beam injectors and gyrotron tubes), Rotating Target Neutron Source II, and a Blanket and Shield Test Facility.

These projects are aimed at providing the fundamental engineering capability for design and fabrication of major components used to build experimental fusion reactors and form the data base for subsequent industrial decisions on demonstration and commercial fusion reactors. Generic technology developed under the Development and Technology programs provided the basis for the successful design and fabrication of the neutral beam heating systems for PDX, PLT, ISX-B, Doublet-III, MFTF-B, and TFTR and the superconducting Ying-Yang magnet on MFTF-B. It is clear that such components would not be designed until the specific experimental project is under way; however, if the development of the supporting technology was not started until the exact need was specified significant delays would be experienced or the approach would not be tried.

Question 7. continued

An additional example is found in superconducting magnet development. The cost of electricity will be a major parameter in operating large tokamaks. Superconducting magnets are seen as a solution to this problem. It will be necessary to test large superconducting magnets in a realistic configuration before a commitment to use them in a large tokamak would be made. This same philosophy is held by the European Community and the Japanese, who have agreed to share the cost for such a test facility. The Large Coil Program is an international cooperative, industrially based effort for the fabrication, testing and evaluation of six large superconducting magnets. The total international investment is over $100 million. This commitment reflects the importance of the knowledge of the performance limits of such devices before major experimental reactors are designed.

8. Mrs. Bouquard. Dr. Trivelpiece, you say that the strategy of the program is to lay the groundwork for a rational assessment of fusion's potential as a practical energy source. How do the decisions to delay MFTF-B, EBT-P and FMIT help lay the groundwork for such a rational assessment of fusion's potential?

Dr. Trivelpiece. Specific program decisions are made in support of this strategy but must also satisfy the near-term constraints, most noticeably yearly budget limits. The decisions to delay MFTF-B, EBT-P and FMIT were made to ensure that the overall program's ability to lay the groundwork for a rational assessment of fusion's practical application was maintained in the face of budgets lower than earlier anticipated.

9.a. Mrs. Bouquard: The Office of Fusion Energy is about to initiate operations in the Tritium Systems Test Assembly, since we have handled significant quantities of tritium in the weapons program for years, why couldn't this knowledge be transferred in toto to the fusion program?

Dr. Clarke: Where applicable, significant use is being made in the fusion program of tritium technology developed in the weapons program. Experienced personnel and generic hardware are being used directly on the TSTA project. However, the weapons program has not had the need to develop a closed loop, steady state processing cycle which would couple directly to a fusion reactor and be capable of processing the reactor exhaust and blanket recovery streams, and the range of impurities which these streams will contain. In addition to meeting these special developmental process requirements, the fusion tritium program must also demonstrate the capability to handle reactor relevant quantities of tritium in safe and environmentally acceptable systems which can be applied to public, unclassified, commercial use.

9.b. Mrs. Bouquard: If it indeed is felt necessary to have operating experience on a working fusion device, why couldn't that experience be obtained during the operating of TFTR?

Dr. Clarke: TFTR will provide valuable, but limited, tritium handling experience. Its process inventory will be only a small fraction of a percent of that of a power-producing fusion reactor, and it will do none of the purification and separation processing required for such a reactor.

10. Mrs. Bouquard. After TFTR has fulfilled its mission of demonstrating scientific feasibility, what does DOE and the Office of Fusion Energy intend to do with this large facility?

Dr. Clarke. Although the demonstration of scientific feasibility ($Q\sim1$) remains the principal focus of the TFTR program, an objective of the Tokamak Flexibility Modification (TFM) effort has been to lay the groundwork for longer pulse, higher power experiments in TFTR that would permit the attainment of $Q\sim2$. It is at this level of fusion power production that sufficient alpha particle heating (the steady state heat source in a reactor) would be produced to permit detailed studies of their interaction with the bulk plasma. The pace and emphasis of this phase of the program is currently under study. In fact, a working group within OFE has been formed to examine the potential uses of the TFTR facility in the post $Q\sim1$ time period (1986-1991). We are considering both the potential role of TFTR in supplying D-T physics (e.g., alpha particle heating), which is of generic interest to the fusion program, as well as the extent to which TFTR (or suitable modifications to the device) could contribute to some of the critical fusion engineering questions of generic interest, such as remote handling, long pulse heating and current drive, heat removal, neutron utilization, etc.

11. Mrs. Bouquard. What are the detailed FY 1981, FY 1982 and FY 1983 objectives, funding levels, and program milestones for each of the budget elements of OFE's Fusion Reactor Materials subactivity, including (1) Alloy Development for Irradiation Performance, (2) Plasma Materials Interactions, (3) Special Purpose Materials Development, (4) Damage Analysis and Fundamental Studies, (5) Radiation Facilities Development and Operation, and (6) Analysis and Evaluation?

Dr. Clarke. The objectives for each of the Material Reactor Program Elements have remained constant over the fiscal years 1981 through 1983 and are as follows:

Alloy Development for Irradiation Performance (ADIP)

The objectives of the ADIP program are to develop and provide advanced materials for commerical fusion power and to provide the radiation damage data necessary to upgrade existing materials for utilization in interim fusion devices.

Damage Analysis and Fundamental Studies (DAFS)

The objective of the DAFS program is to develop necessary procedures and supporting technology for the applicatin of irradiation data obtained in neutron and charged paricle environments to the expected fusion reactor environment.

Plasma/Materials Interaction (PMI)

The objectives of the PMI program are to provide the data base necessary to deal with the impurity problem and to minimize the effects on first wall materials due to interaction with the hot plasma.

Special Purpose Materials (SPM)

The objective of the SPM activity is to address materials problems not addressed by other problem activities. Materials assessment and development in this area include insulators, materials for high-field (>10 T) superconducting magnets, coolants, breeding materials, neutron multipliers, barriers for tritium control, materials for antennas and waveguides, graphite and SiC, heat-sink materials and current breakers for tokamaks.

Radiation Facilities Development and Operation (RFDO)

The objective of the RFDO activity is to develop and operate the irradiation testing facilities that are required to conduct the Fusion Reactor Materials program.

Analysis and Evaluation (A&E)

Organize and categorize all pertinent information on Materials Handbook to support fusion reactor design and to serve as a communication link between the design community and the materials research community.

The funding level for the Materials Program is as follows:

($'s in K)

	FY 1981	FY 1982	FY 1983
	BA	BA	BA
ADIP	4407	4295	5100
FMI	2870	3065	3105
SPM	840	1865	1395
DAFS	2148	2165	2350
RADIATION FACILITIES	1900	3500	3650
RTNS-II	(1000)	(2020)	(2000)
ORR	(750)	(800)	(1650)
HFIR	(0)	(600)	-
FUEL INVENTORY	(150)	-	(0)
A&E	-	100	100
TOTAL	12165	14390	15700

The program milestones for these areas are as follows:

Alloy Development for Irradiation Performance (ADIP)

FY 1981

- Initiated the scale-up of long-range ordered alloys which have potential for long-term high performance applications to fusion reactor systems, a scale-up from laboratory quantities to methods that are appropriate for industrial production of this promising category of radiation resistant alloys.

- Completed the scoping test evaluation of the non-stainless steel iron base (Path-B) alloys, and selected the leading Path-B alloys for the further development in the ADIP program.
- Initiated a joint US/Japan program in the study of the irradiation response of fusion structural alloys.

FY 1982

- Complete the scoping test evaluation of the Path-B, Fe-Ni-Cr alloys, and select the leading Path-B alloys for further development in the ADIP program.
- Complete the initial assessment of the influence of radiation damage on the fracture behavior of the ferritic stainless steels. This will provide an early guide as to the potential suitability of that class of alloys for fusion reactor applications.
- Complete evaluation of first spectral tailoring experiment simulating the fusion reactor environment.

FY 1983

- Determine suitability of upgraded stainless steels for the next fusion device.

Damage Analysis and Fundamental Studies (DAFS)

FY 1981

- Completed first fission-fusion correlations for stainless steels.
- Identified critical parameters for the effects of helium on grain boundary embrittlement.

FY 1982

- Complete evaluation of RTNS-II irradiation of stainless steel at a minimum 14 MeV fluence of 10^{19} n/cm^2.
- Establish coordinated mechanical behavior program directed at improving basis for fission-fusion correlations.

FY 1983

- o Complete determinations of helium production cross sections.
- o Complete models of displacement damage production.

Plasma/Materials Interaction (PMI)

FY 1981

- o Characterized the thermal aspect of plasma disruptions in tokamaks via post-exposure materials analysis.
- o Characterized the plasma boundary region in ISX, PLT and TMX using solid state probes and nuclear analysis techniques.

FY 1982

- o Develop and test thick (1-2 mm) coatings of low-Z materials for plasma interactive components.
- o Complete the initial characterization of the chemical interaction of graphite to plasma irradiation over the temperature range of 1200K to 2000K.
- o Test actively cooled, coated limiters in Doublet III.
- o Conduct first US experiments in Doublet III and TEXTOR.

FY 1983

- o Select candidates for high heat load materials for application in the next fusion device.
- o Formulate preliminary surface physics and plasma edgfe models as a first step for a comprehensive solid surface plasma transport model.

Special Purpose Materials (SPM)

FY 1981

- o Initiated irradiation testing of blanket breeder materials.
- o Initiated irradiation testing of polyimide organic insulators for fusion magnets.

FY 1982

- o Initiate irradiation testing to determine the difference between neutron and gamma effects in organic insulators.
- o Determine critical life-limiting component of fusion superconducting magnets.
- o Obtain first results from solid breeder development tests.
- o Complete initial radiation damage test on moderate dose polyimide insulators for fusion magnets.

FY 1983

- o Initiate testing on high dose organic insulators.
- o Initiate irradiation tests on inorganic ceramic insulators for near-plasma normal magnets.

Radiation Facilities Development and Operation (RFDO)

FY 1981

- o Begin tests on large targets for RTNS-II.

FY 1982

- o Begin US/Government of Japan joint operation of RTNS-II facility.
- o Complete testing of large targets on RTNS-II.
- o Initiate discussions with Japanese and Europeans regarding joint funding and utilization of FMIT.

FY 1983

- o Initiate large target procurement for RTNS-II.

Analysis and Evaluation (A&E)

FY 1981

- o Completed the initial preparation of data sheets for the influence of fusion-like irradiation conditions on the properties and behavior of the structural alloys for inclusion in the initial edition of the Materials Handbook for Fusion Energy Systems.

FY 1982

- o To add necessary near-term data on critical component materials in each of the eight chapters of the Fusion Materials Handbock.

FY 1983

- o To provide complete data set on two materials in each of the eight chapters of the Fusion Materials Handbook.

12. Mrs. Bouquard: What are the detailed FY 1981, FY 1982, and FY 1983 objectives, funding levels, and program milestones for each of the budget elements of OFE's Fusion Systems Engineering subactivity, including 1) Conceptual Design and Engineering, 2) Feasibility Assessment, 3) Blanket and Shield Engineering, 4) Tritium Processing and Control, 5) Plasma Systems, and 6) Plant Systems?

Dr. Clarke: The objectives, funding levels and program milestones for each of the Fusion Systems Engineering subactivity elements are the following:

1. Conceptual Design and Engineering

Funding (B/A, $M)	FY81	FY82	FY83
	1.390	.380	5.350

Objective

The Conceptual Design and Engineering subactivity provides engineering and technology support for projects in the early conceptual phases of their development. These efforts are directed at fusion devices which are being considered for the next generation of experiments leading eventually to commercial reactors.

Milestones

FY81

- o Organize, manage and participate in USA INTOR conceptual design activity
- o Complete Neutral Beam design for Zephyr
- o Complete selection of tandem mirror next step (TMNS) end cell configuration

FY82

- o Continue INTOR involvement
- o Complete Mission Statement for TMNS and select preliminary parameters

FY83

- o Identify critical issues and evaluate effect of TMX-Upgrade results for TMNS design

In FY83, activities related to design development of the Fusion Engineering Device (FED) concept have been budgeted within the Conceptual Design and Engineering subactivity. The objective of this activity is to develop the preconceptual design of FED and to prepare for FED construction and initiation of major supporting research and development. Milestones for FY83 include incorporation of latest experimental plasma physics results and modest refinement of the FED reference design and principal alternates.

2. Feasibility Assessment

Funding (BA, $M)	FY81	FY82	FY83
	3.318	3.730	4.690

Objective

In the area of Feasibility Assessment the objectives are to make technological and commercial feasibility assessments of various fusion reactor concepts by designing commercial-sized reactors; provide a realistic baseline for fusion reactor subsystem designs; and to identify data and performance requirements for plasma confinement and technology development which can be used in planning future program directions.

Milestones

FY81

- Complete Elmo Bumpy Torus (EBT) Level I Commercial Reactor Design Study
- Complete SATYR study of D-D Fueled Tandem Mirror Reactor and WILDCAT study of D-D fueled Tokamak reactor to provide input for assessment of the viability of advanced fuels
- Complete preliminary conceptual study of a commercial Modular Stellarator Reactor (MSR)
- Complete evaluation of supplemental plasma heating systems for tokamaks by comparing radio-frequency heating with neutral beam heating

FY82

- Complete the design study for a tokamak reactor which will demonstrate features and subsystems extrapolatable to commercial use and show that the risk of developing a first commercial reactor is acceptable (STARFIRE DEMO)

- o Complete preliminary assessment of reactor designs which use materials that have low induced radioactivity properties
- o Complete optimizatiion of magnetics design of Modular Stellarator Rector study
- o Complete definition of Compact Reverse Field Pinch Reactor design point

FY83

- o Complete the Mirror Advanced Reactor System Commercial Design Study (MARS)
- o Complete the Modular Stellarator Reactor Commercial Design Study
- o Complete Compact Reverse Field Pinch Reactor Study

3. Blanket and Shield Engineering

Funding (BA, $M)	FY81	FY82	FY83
	2.127	3.460	3.750

Objective

The Blanket and Shield Engineering element covers the development of fusion reactor blanket and shield systems. The program objective is to provide a technology base for structural, thermal, electromagnetic, nuclear and tritium breeding design of first wall, blanket and shield components and systems. In the near term, the program will emphasize support of the FED design and will develop the prerequisite data base for DEMO and commercial fusion reactors.

Milestones

FY81

- o Complete contracting of First Wall, Blanket and Shield Engineering tasks through ANL, which serves as lead technical organization
- o Complete design specifications for tritium breeding TRIO-01 experiment containing $LiAlO_2$.
- o Complete first experiment on neutron streaming through shielding ducts

FY82

- o Begin first wall component testing under simulated surface heat fluxes at ESURF facility and complete larger ASURF facility

- Initiate in-pile irradiation of TRIO-01 experiment
- Initiate nuclear data evaluation program

FY83

- Complete construction of FELIX electromagnetic effects test stand
- Complete TRIO-01 testing and design specifications for TRIO-02 experiment
- Complete second experiment on neutron streaming through shielding ducts

4. Tritium Processing and Control

Funding (BA, $M)	FY81	FY82	FY83
	3.037	2.850	2.610

Objective

The objectives of the Tritium Processing and Control element are to develop and demonstrate the technology base for operating a prototypic fusion reactor fuel cycle system and to demonstrate the ability to control, contain and safely handle reactor-relevant quantities of tritium.

Milestones

FY81

- Initiate testing of prototypic tritium monitor which differentiates on a real time basis between tritium gas and tritiated water
- Complete installation and begin testing of Isotope Separation system for TSTA

FY82

- Complete construction and begin initial operation of the Tritium Systems Test Assembly (TSTA)
- Initiate experimental program at TSTA

FY83

- Demonstrate full scale steady-state, integrated closed loop operation of fusion reactor D-T fuel cycle in TSTA
- Complete initial evaluation of alternate Fuel Cleanup System process lines

5. Plasma Systems

Funding (BA, $M)	FY81	FY82	FY83
	.650	.450	.400

Objective

The Plasma Systems subactivity provides theory and computer code development that relates the plasma physics parameters to the engineering requirements for fusion devices. These codes are used in the conceptual design of both experimental devices and commercial reactors.

Milestones

FY81

- Complete scoping study of basic hybrid divertor concept
- Complete development of impurity control code by electric fields for plasma transport

FY82

- Complete integrated engineering and physics analysis needed to evaluate the hybrid divertor concept
- Validate impurity flow reversal code by comparison to ISX-B and PLT experiments

FY83

- Complete application of impurity flow reversal code to analyze the possibility of using this approach by neutral beam injection in FED

6. Plant Systems

Funding (BA, $M)	FY81	FY82	FY83
	200	250	300

Objective

The Plant Systems subactivity provides design, engineering and technology support for those portions of a fusion reactor which are not directly related to the plasma.

Milestones

FY81

- Completed study which surveyed the status of radiation hardening for diagnostics, identified problem areas and recommended further actions

FY82

- Submit radiation hardening for diagnostics experimental requirements to FMIT
- Develop limiter and first wall designs using low activation materials

FY83

- Conduct first radiation hardening experiment
- Complete conceptual design of a low activation blanket module for FED

13. Mrs. Bouquard: Dr. Trivelpiece, your March 22, 1982, response to the Subcommittee's request for detailed funding profiles for each of OFE's major budget activities for FY 1979 - FY 1983, provided us with actual and estimated BAs down to the individual budget element or task/subtask level. For each of FY 1982 and FY 1983, please provide a detailed funding profile of the performers of each of these budget elements.

Dr. Trivelpiece: The following is a funding profile of the major fusion contractors performing research, development, fabrication, and construction activities in FY 1982 and FY 1983.

Magnetic Fusion Energy
(Budget Authority)

	($ in thousands)	
	Estimate FY 1982	Estimate FY 1983
Argonne National Laboratory	$ 6,848	$ 6,146
Brookhaven National Laboratory	1,418	1,460
Hanford Engineering Development Laboratory	16,005	2,380
Idaho Nuclear Engineering Laboratory	1,715	1,900
Lawrence Berkeley Laboratory	8,407	9,182
Lawrence Livermore National Laboratory	93,160	96,270
Los Alamos National Laboratory	19,514	20,009
Oak Ridge National Laboratory	91,732	79,180
Pacific Northwest Laboratory	259	300
Sandia Laboratories	3,320	3,250
Princeton Plasma Physics Laboratory	128,231	130,947
General Atomic	23,379	28,885
Massachusetts Institute of Technology	19,800	23,351
Wisconsin, University of	3,835	3,402
Texas, University of	5,437	5,835
Maryland, University of	1,505	1,600
UCLA	3,928	4,418
All Other Universities	7,179	6,914
All Other	14,812	18,671
Total Magnetic Fusion Energy	$450,484	$444,100

14. Mrs. Bouquard. What is the present capability of the Office of Fusion Energy to adequately test and evaluate candidate first wall and blanket materials in a realistic fusion reactor environment? Please identify facilities currently used (e.g., RTNS-II, HIFR, ORR, etc.), as well as models which give one confidence that one can extrapolate current work to reactor-like conditions.

Dr. Clarke. At present no neutron irradiation facility exists which, by itself, fully simulates the fusion reactor environment; for this reason, our fusion materials irradiations program takes advantage of several presently available neutron and particle irradiation facilities, each of which simulates some characteristics of the fusion enviornment.

1. Fission Reactors

Fusion alloy development and evaluation programs aimed at radiation resistant materials require large irradiation volumes. At present, such facilities exist only in fission reactors where neutron energies are significantly below the energy of neutrons produced by fusion reactors. For nickel-bearing alloys, such as stainless steels, it is possible to approximate the impact of helium generation as well as total neutron exposure using the fission reactor neutron energy spectrum. Fission reactors currently being used for this purpose in the fusion program include:

(1.) Oak Ridge Reactor (ORR)

(2.) High Flux Isotope Reactor (HFIR)

(3.) Experimental Breeder Reactor-II (EBR-II)

2. D-T Neutron source

RTNS-II is a test facility that produces neutrons of the proper energy (14 MeV) for simulating a fusion reactor environment; it is limited by both irradiation volume and maximum flux. The volume that sees the maximum flux (1×10^{13} n/cm^2/sec) is approximately 1 cm^3. This facility is being utilized for damage energy determinations, low fluence microstructural evolution and fission-fusion correlation modelling. End-of-life studies are being carried out in RTNS-II for low fluence critical components such as magnet insulators and stabilizers. At present the RTNS-II is being utilized to develop data for correlating the effects of high energy fusion neutrons with low energy fission damage at low to medium fluences. Combined with our ability to better simulate the fusion environment for Ni-bearing alloys in fission reactors, we have confidence that adequate testing and verification can be achieved for these materials using fission reactors and RTNS-II over the next decade. Engineering testing and verification of advanced, non-Ni-bearing alloys for commerical fusion reactors will not be possible until FMIT is built and operating for several years.

15. Mrs. Bouquard. What is the current status and how much has been expended to date, by fiscal year, on the EBT-P device and the FMIT facility?

Dr. Trivelpiece. The current status for EBT-P is that the Title I design was recently completed. The project is in the early stages of Title II design with supporting R&D activities. No construction activity has been authorized or started.

The funding history of EBT-P is shown in the following table:

	Funds Obligated ($M)		Funds Spent ($M)	
Funding	PACE	OPEX	PACE	OPEX
FY				
79	--	1.6	--	1.6
80	2.0	2.4	0	2.4
81	5.4	2.0	4.9	2.0
82 (thru March)	13.4	4.0	2.5	2.2
Total	20.8	10.0	7.4	8.2

The status of the FMIT project is that most of the research and development has been completed. The assembly and testing of the 2MEV accelerator front end remains to be done. Facility design completion ranges from 100% complete for the building and utilities to approximately 50% complete on the experimentatal facilities.

The funding history of FMIT is shown in the following table:

	Funds Obligated ($M)		Funds Spent ($M)	
Funding	PACE	OPEX+CE	PACE	OPEX+CE
FY				
77	--	1.0	--	.9
78	7.5	3.2	.1	3.0
79	6.9	8.5	3.8	7.3
80	10.0	11.1	8.0	10.2
81	8.6	8.4	12.6	10.0
82 (thru March)	9.0	5.0	5.3	1.8
Total	42.0	37.2	29.8	33.2

16. Mrs. Bouquard. a) Dr. Trivelpiece, are you familiar with the INESCO Corporation, the people who are privately developing a small fusion reactor?
b) Is INESCO a technically credible company?
c) How does their program relate to DOE fusion programs?

Dr. Trivelpiece. I am not familiar with the INESCO Corporation at present. Based on the credentials and ability of the people working for the company, INESCO was technically credible when they were under contract with the Department. Although we have heard that several more good people have been hired by INESCO since that time, we have not had further interaction with INESCO and are not in a position to judge their current capabilities.

The INESCO program is based on an extension of the Alcator line of small, high field, high plasma density tokamaks which were developed under Department funding. The Department also funded the initial design work on INESCO's Riggatron concept through a 9 month, approximately $639,000 preconceptual design study. The results of the evaluation of this study were provided to Congress as enclosures to letters from Robert D. Thorne, DOE Assistant Secretary for Energy Technology, to Representatives Mike McCormack and Manuel Lujan in July 1978, and in a letter from Edwin E. Kintner to Senator S. I. Hayakawa on September 29, 1978. In summary, the result of the evaluation was that the chance of success of the Riggatron concept was too small to justify further funding by the Department.

As a result, the INESCO and Department programs are complementary efforts with the Department's program focused primarily on somewhat larger, lower field, lower density devices. The Department is also funding a modest amount of research on the compact toroid concept, which is potentially even smaller than INESCO's Riggatron, in an effort to develop a qualitatively improved fusion confinement concept.

17. Mrs. Bouquard. Are there any synergisms between the DOE and INESCO programs which can help advance the generic U.S. fusion efforts?

Dr. Trivelpiece. Since INESCO is now a privately funded venture, they are not required to make their findings known to the Government and are not doing so. Conversely, the data developed by the Department's fusion program is available to the general public for use, including INESCO. Thus the information flow is currently a one way operation. However, since INESCO is a U.S. corporation, this still works to the advantage of the overall effort to develop fusion for use by the country.

18. Mrs. Bouquard. If INESCO is successful in 5 years as they claim, what impacts will this have on the DOE program? Can the U.S. profit from their success?

Dr. Trivelpiece. If INESCO is successful in producing a working fusion power reactor that can be judged to become economically competitive and environmentally acceptable, then the Department's fusion program can be terminated. INESCO will have demonstrated that private capital has the capacity to complete the job of developing fusion and that Government support is unnecessary.

The country would certainly profit in the same manner it does when any U.S. firm is successful in developing a new and marketable product. In this case, the benefits would be even greater since the successful commercialization of fusion will assure the nation and the world of the availability of an almost limitless source of energy and reduce our dependence on foreign energy sources.

19. Mrs. Bouquard. What is the DOE policy concerning the transition of research data to the private sector?

Dr. Trivelpiece. It is DOE policy that technology transfer activities as required by Public Law 96-480 (the Stevenson-Wydler Technology Innovation Act of 1980) are legitimate functions of the R&D laboratories and will be conducted, as appropriate, at those laboratories (including all the fusion laboratories).

Technology transfer is understood here to mean the transformation of R&D into processes, products, and services that can be applied to State and local government and private sector needs. The R&D laboratory technology transfer program emphasizes personal interaction between the technical staff of the R&D laboratories and representatives of the public and private sectors. The R&D laboratory technology transfer program includes the following activities:

(1) Assessment of R&D projects for applicability to the needs of the private sector and State and local governments.

(2) Application and/or adaptation of research or technology into processes, products, and services for use by the private sector and State and local governments.

(3) Technical assistance to the private sector and State and local governments in adapting federally developed technology for use.

(4) Cooperation with any institution or organization which provides linkage between the R&D source and the public or private sector utilizing the R&D to move technology from the laboratories to the private sector and State and local governments.

(5) Licensing of DOE-owned patented technology for commercial use.

20. Mrs. Bouquard: It has been said that the goal of the Magnetic Fusion Energy Program should not be to achieve the "highest potential" of fusion for this pursuit is likely to lead to an extended and needless development of excessive R&D components, systems, and test facilities, without effective relationship to the more goal-oriented projects. Rather, the goal should be to produce fusion-generated electrcity which is safe, reliable, environmentally compatible, and, hopefully, economically competitive--a worthwhile goal clearly related to our national interest and needs. Please comment on this statement, and, also, tell me how OFE ensures that, given such a broad goal as assessing fusion's highest potential, the program is being properly focused?

Dr. Clarke: I have no argument that the goal of the Federal fusion program should be to produce an electricity generating system which is safe, reliable, environmentally compatible, and economically competitive. The phrase, "achieving the highest potential of fusion", which was coined by the Foster Group in 1978, is merely a succinct statement of this universally accepted goal. We are pursuing this goal in our R&D program by continually reassessing the practical reactor relevance of our scientific concepts and engineering technologies in the light of advanced reactor systems designs. In my testimony, I indicated that the number of scientific concepts being pursued has been reduced over the last ten years. In addition, our increased understanding of the technology requirements of practical fusion reactors has led us to concentrate on a limited set of largely generic technologies in light of these systems studies. The magnetic fusion program is being focused toward a practical product as can be seen from the large reduction in the number, size and complexity of our reactor concepts and embodiments over the last decade.

21. Mrs. Bouquard: Dr. Clarke, in a letter dated March 11, 1982, Under Secretary Fiske informed the Subcommittee that Magnetic Fusion Energy FY 1982 funds totaling $2,573,000 were being deferred, including $642,000 in Applied Plasma Physics, $743,000 in Confinement Systems, $819,000 in Development and Technology, and $115,000 in Planning and Projects. Please provide the Subcommittee with the detailed breakdowns of the program elements which absorbed these deferrals, as well as a breakdown of the performers affected.

Dr. Clarke: In order to accommodate Magnetic Fusion Energy's portion of the general reduction of $49 million contained in the Energy Supply R&D Operating Appropriation for FY 1982 the following program elements were affected:

Applied Plasma Physics	- $100,000 from ZT-40
	- $100,000 from computer network
	- $100,000 from Fusion Power Research Facility
	- $63,000 Headquarters uncommitted funds
	- $279,000 from theory program
Confinement System	- $695,000 from TFTR facility operations
	- $48,000 from Headquarters uncommitted
Development & Technology	- $200,000 from magnet program
	- $370,000 from materials R&D
	- $100,000 from TSTA operations
	- $30,000 from Reactor Safety Research
	- $119,000 from Headquarters uncommitted
Planning & Projects	- $115,000 from Headquarters uncommitted
Program Direction	- $254,000 from Headquarters uncommitted

The following is an indication of the allocation of the reduction by contractor:

Summary by Contractor

Lawrence Livermore National Laboratory	$- 147,000
Los Alamos National Laboratory	- 244,000
Oak Ridge National Laboratory	- 281,000
Lawrence Berkeley Laboratory	- 30,000
Princeton Plasma Physics Laboratory	- 757,202
General Atomic	- 51,000
Idaho Nuclear Engineering Laboratory	- 30,000
University of Texas	- 115,000
New York University	- 19,000
Headquarters Uncommitted	- 898,798
	$-2,573,000

Department of Energy
Washington, D.C. 20585

April 28, 1982

Honorable Harold C. Hollenbeck
House of Representatives
Washington, D.C. 20515

Dear Mr. Hollenbeck:

Following the March 23, 1982, hearing on magnetic fusion energy, before the House Science and Technology Subcommittee on Energy Research and Production, you submitted questions to Dr. Alvin Trivelpiece to supplement the record. Enclosed are answers to the questions you submitted.

Copies of the responses have been sent to Dr. Harlan Watson of the Subcommittee staff.

If you have any questions, please call Ingrid Nelson or Tom Pretorius of my staff on 252-4277. They will be happy to assist you.

Sincerely,

Thomas H. Pretorius
for
Robert G. Rabben
Assistant General Counsel
for Legislation

Enclosures

cc: Dr. Harlan Watson
Subcommittee Staff on Energy
Research and Production

QUESTIONS SUBMITTED FOLLOWING

the

MARCH 23, 1982 HEARING

before the

COMMITTEE ON SCIENCE AND TECHNOLOGY
SUBCOMMITTEE ON ENERGY RESEARCH AND PRODUCTION

MAGNETIC FUSION PROGRAM
DEPARTMENT OF ENERGY

1. Mr. Hollenbeck. Will TFTR be supported with adequate operating funds in FY 1983 and 1984 so that the schedule can be maintained for demonstrating break-even capabilities in 1985?

Dr. Clarke. The FY 1983 operating funding level identified in the Congressional budget is adequate in support of the breakeven demonstration operations which start at the end of 1985. This demonstration is of highest priority in the magnetic fusion program, and the FY 1984 operating budget request will also reflect this.

2. Mr. Hollenbeck. Will DOE continue to support a sufficiently broad and vigorous program so as to exploit the success of the tokamak in reaching the reactor regime?

Dr. Clarke. The Department of Energy will continue to support a program which fully exploits the success of the tokamak in reaching the reactor regime. The toroidal program which includes the simple tokamak has embarked upon a program to optimize toroidal reactors. Since the major reactor deficiency of the simple tokamak is its pulsed nature, methods of making truly steady state toroidal reactors are being pursued.

Presently we have demonstrated the principle of steady state tokamak operation on the PLT tokamak using rf current drive. The ATF facility at ORNL will demonstrate the steady state stellarator/torsatron approach with reactor level plasmas. The toroidal program's goal is to be ready to proceed with an optimized toroidal demonstration reactor following the FED.

3. Mr. Hollenbeck. Will the high productivity of the PLT/PDX research complex at Princeton be maintained?

Dr. Clarke. Yes. PLT will continue to be the lead facility in the development of radio frequency (rf) heating methods and the principles of rf current drive which can lead to an attractive steady state tokamak. The power level in the ion cyclotron resonance frequency (ICRF) experiments will be raised to 3-5 MW from its present value of about 2 MW. The pulse length of lower hybrid frequency (LH) driven discharges will be increased to about ten seconds from its present limit of one second. Particle and impurity control experiments and the investigation of high beta plasmas will be continued on PDX. Since PLT and PDX share power supplies, it is not possible to operate them simultaneously. The allocation of operating time between them in FY 1983 will be based on an assessment of the programmatic needs of the overall tokamak program.

4. **Mr. Hollenbeck.** Could the intent of the Magnetic Fusion Energy Engineering Act of 1980 begin to be fulfilled during this decade by utilizing the TFTR facility as a test bed for fusion engineering?

Dr. Clarke. A working group within OFE has been formed to examine the potential uses of the TFTR facility in the post Q ∼1 time period (1986-1991). We are considering both the potential role of TFTR in supplying D-T physics (e.g., alpha particle heating), which is of generic interest to the fusion program, as well as the extent to which TFTR (or suitable modifications to the device) could contribute to some of the critical fusion engineering questions of generic interest, such as remote handling, long pulse heating and current drive, heat removal, neutron utilization, etc.

5. **Mr. Hollenbeck. What is the Department doing to encourage constructive innovation? Please describe new directions and recent discoveries. Are we searching hard enough so that we can be reasonably sure of identifying the best route to fusion power?**

Dr. Clarke. The Department of Energy's policy is to develop the highest potential of fusion, i.e., to develop the most attractive fusion systems rather than to take the quickest route to a fusion reactor.

In the implementation of this policy, the Department places a strong emphasis on improvements in the mainline tokamak and mirror concepts and on emerging fusion concepts that will lead to attractive, economical fusion systems. Innovation is obviously important to these activities and is encouraged throughout the fusion program. Some of the new directions and recent discoveries are described below.

In the tokamak area we have broadened our approach by organizing our program to develop the most attractive toroidal system rather than the tokamak per se. Such a toroidal system might include features of the tokamak combined with ideas taken from stellarators or other toroidal approaches. We currently plan to fabricate a modest sized device called the Advanced Toroidal Facility-1 at the Oak Ridge National Laboratory which will incorporate as many as possible the best features of toroidal devices.

One recent important discovery in toroidal research is the use of radio frequency energy to drive a steady-state current in a tokamak. This idea was conceived in our theory program, tested initially on a small-scale university tokamak, and then demonstrated on the Princeton Large Torus. The importance of this discovery is that tokamaks can now potentially be steady-state rather than pulsed reactor systems which greatly simplifies the engineering, reduces cost and improves reliability.

Another important development in the toroidal program is the invention of modular helical coils for stellarator-like configurations. This discovery combined with recent promising experimental results from Germany and Japan suggests that a stellarator-like toroidal system may lead to an attractive, steady-state reactor.

Substantial innovation and advances have occurred in the magnetic mirror program. At one time it was questionable whether a power producing reactor could be made based on the mirror concept. During the past several years there have been a number of inventions which have made the mirror into an attractive system. The first and most important invention was the tandem mirror concept in which the end losses from a cylindrical magnetized plasma column were greatly reduced by a magnetic mirror placed at both ends of the column. The plasma confinement principles of the tandem mirror were demonstrated on the TMX device at the Lawrence Livermore National Laboratory (LLNL). Since then there have been several more inventions such as thermal barriers and simplified magnetic geometries which improve the energy economics and reduce the technology requirements and cost of the tandem mirror. These new ideas will be demonstrated in new devices - TMX-Upgrade recently constructed at LLNL and TARA being constructed at MIT.

The bumpy torus fusion concept represents a hybrid mirror/torus approach which has attractive features such as steady-state operation and modular construction. The Department had planned an aggressive development effort on this concept with the construction of the EBT-P device by ORNL and McDonnell Douglas. However, due to the present budget restrictions this project has been slowed.

The Department also supports an activity which is specifically aimed at testing innovative fusion concepts. This activity is called Advanced Fusion Concepts and a budget of $18.9 million has been requested for this work in FY 1983. Within this activity the primary emphasis is on developing compact fusion systems and the bulk of the funding is spent on the reversed field pinch and the compact toroid.

The power density, i.e., the power produced per unit volume of power plant material, is an important factor in power plant economics. Recent reactor studies of the reversed field pinch suggest that power densities as high as those in light water reactors may be possible. Results from the ZT-40 reversed field pinch device at the Los Alamos National Laboratory have also substantially exceeded expectations further supporting the promise of this approach.

Another approach, the compact toroid, offers the promise of a compact, simple system. The compact toroid has the good energy confinement properties of a toroidal system but has a simple geometry with no magnetic field coils linking the plasma. Research on this concept was increased to its present modest level only a few years ago after initial encouraging theoretical and experimental results.

It should be noted that the theoretical activities and our small university experiments play an important role in conceiving and testing new ideas. Small experiments which can be modified inexpensively and whose programs can be redirected easily play a key part in the initial tests of a new idea.

In summary, innovation is strongly encouraged in the fusion program and is an important element in implementing the Department's strategy for developing fusion power. I have described some of the innovation, new directions and recent discoveries in the magnetic confinement of plasmas. However, innovation and new discoveries are equally prevalent and encouraged in other portions of our program such as materials development, superconducting magnet development, reactor studies, diagnostic development, etc. I believe that the present program is searching hard enough to ensure that the best route to fusion power is identified.

6. Mr. Hollenbeck. In light of DOE proposals, can the United States maintain its leadership of the International fusion program?

Dr. Trivelpiece. The United States intends to maintain its leadership in the international fusion program even in the face of budgets lower than earlier anticipated. This situation requires a closer management look at the use of international collaboration in the program. In this changed circumstance, international cooperation efforts are being oriented toward those areas in which the U.S. can benefit in terms of maintaining comprehensiveness and of managing expansion into new areas of technology and engineering. We expect that through technical innovation, learning from systems integration activities, practicing hard bargaining for equitable cooperative agreements and applying strict management principles within projected budgets we will be able to maintain our leadership.

APPENDIX II

ADDITIONAL MATERIAL SUBMITTED FOR THE RECORD

THE SECRETARY OF ENERGY
WASHINGTON, D.C. 20585

August 24, 1982

Honorable Marilyn Lloyd Bouquard
Chairman, Subcommittee on Energy
  Research and Production
Committee on Science and Technology
House of Representatives
Washington, D.C. 20515

Dear Mrs. Bouquard:

During the Magnetic Fusion Energy program's FY 1983 budget hearing before your Subcommittee on March 23, 1982, you raised a question regarding the status of the Comprehensive Program Management Plan. At that time, it was indicated that an interim report would be provided in a couple of months.

In response to your interest, enclosed for your information is a copy of a letter which has recently been sent to the relevant Congressional Committees which provides a synthesis of the latest thinking that lies behind the current development of the Comprehensive Program Management Plan. We are confident that the final plan will be ready for submittal by October 1, 1982.

Sincerely,

James B. Edwards

James B. Edwards

Enclosure

THE SECRETARY OF ENERGY
WASHINGTON, D.C. 20585

August 6, 1982

RECEIVED
AUG 10 1982
COMMITTEE ON SCIENCE
AND TECHNOLOGY

Honorable Don Fuqua
Chairman, Committee on Science
and Technology
House of Representatives
Washington, D. C. 20515

Dear Mr. Chairman:

As indicated in my letter to you on March 22, 1982, we are preparing a Comprehensive Program Management Plan (CPMP) for the development of magnetic fusion energy to be submitted to Congress by October 1, 1982. The Department has been addressing the major issues to be covered in the CPMP within the context of the Administration's budget and fiscal policies. This letter gives a synopsis of the considerations upon which we are developing our plan, together with a brief outline of the plan's essential features.

The Magnetic Fusion Energy Engineering Act of 1980 (Public Law 96-386, 42 U.S.C. 9301-9312) defined a specific mission objective that required a significantly accelerated program, and thus a substantial near-term growth in budget. However, the economic conditions have been such that substantially increased near-term funding for fusion is unlikely, so that we must examine new approaches to meet the intent of the Act.

We interpret the Act's intent to be the development of a sufficient understanding of the fusion process by the turn of the century to determine if fusion energy should be commercialized and, if so, how. The plan that we are developing addresses this goal and is based, in part, on the following considerations:

- Near-term funding will be less than previously contemplated.
- Near-term program efforts will be focused on critical feasibility issues.
- Near-term fusion technology development efforts will use existing facilities.
- The program will be structured so that its activities can be accelerated if increased funding becomes available.

We believe that the most effective fusion program would have two phases in addition to the present "scientific feasibility" phase. One of these is a product definition phase that would then lead to a product development phase.

Product Definition - This phase will involve first making choices among current advanced plasma confinement systems and later among the several backup systems. Selection from among the advanced pulsed tokamak, steady-state tokamak, and the tandem mirror systems is planned for about 1988. The selection among the bumpy torus, stellarator or reversed-field pinch backup options would be made a year or two later. The goal is to arrive at a final system choice at about the beginning of the next decade. During this phase choices would also be made in the various technology development activities, to focus on critical feasibility issues.

During this phase an Engineering Test Reactor (ETR) will be designed. The ETR is intended to demonstrate the engineering feasibility of fusion. The ETR design will initially be similar to the present Fusion Engineering Device (FED) design, and will gradually evolve into a prototype of the fusion demonstration power reactor (DEMO) as more information becomes available. The reference ETR design will be upgraded periodically to include the most advanced understanding. In this way, the project can be started with minimum delay at any time.

Product Development - During the following two decades (beginning in the early 1990's) the data base required for construction of commercial fusion power reactors will be developed. This development would be partially accomplished in the first of these decades as a by-product of the process of designing the test program to be conducted by the ETR. The first decade will be a time of increasing involvement by industry, primarily through the ETR design and construction process. In the second decade of this phase, the intent will be to transfer as much of the funding as is possible from Federal to private sources.

Over the past decade and a half, progress in the magnetic fusion program has been rapid and encouraging. The experimental demonstration of energy breakeven is expected in early 1986. The development of fusion technology has also been encouraging. We believe that these accomplishments warrant a structured program leading to the development of fusion reactors. The Department's CPMP will outline such a program.

In the near future, we will continue to refine this plan and to seek opinions on it from members of the magnetic fusion research and development community.

Sincerely,

James B. Edwards

James B. Edwards

Enclosure:
March 22 letter

cc:
Honorable Larry Winn, Jr.
Ranking Minority Member

GLOSSARY OF FUSION ENERGY

absolute instabilities: a class of plasma instabilities growing exponentially with time at a point in space in contrast to convective instabilities.

activation: process of making a material radioactive by bombardment with neutrons, protons, or other nuclear particles; also called radioactivation. (See **activation analysis.**)

activation analysis: method for identifying and measuring chemical elements in a sample of material. Sample is first made radioactive by bombardment with neutrons, charged particles, or gamma rays. Newly formed radioactive atoms in the sample then give off characteristic nuclear radiations (such as gamma rays) that tell what kinds of atoms are present and how many.

activity: radioactivity.

adiabatic compression: compression (of a gas, plasma, etc.) not accompanied by gain or loss of heat from the outside. For a plasma in a magnetic field, a compression slow enough that the magnetic moment (and other adiabatic invariants) of the plasma particles may be taken as constant. [Fig. 1]

adiabatic invariant: parameter of the motion of a charged particle in a magnetic field, which remains constant when the variations of the magnetic field in space and time are sufficiently slow.

aftercooling: cooling of a reactor after it has been shut down.

afterglow: transient decay of a plasma after the power has been turned off. When the plasma temperature has become sufficiently cool, the free electrons combine with the ions resulting in the emission of recombination radiation.

Alcator: toroidal confinement device at Massachusetts Institute of Technology designed and operated to produce plasmas with relatively high current and particle densities. Typical design parameters involve a relatively small major radius and high magnetic fields, both for the toroidal magnet and the air core transformer systems. [Fig. 2]

Alfvén velocity: phase velocity of the Alfvén wave.

Alfvén waves: waves of a much lower frequency than the ion cyclotron frequency occurring in a

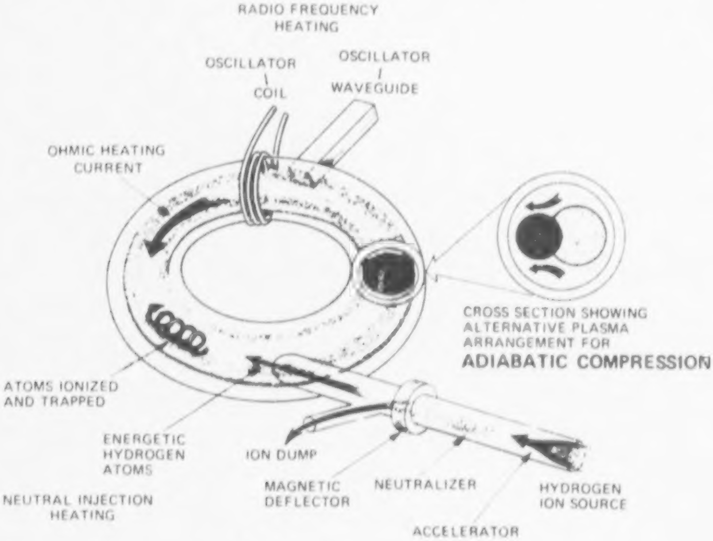


Fig. 1 Main heating systems for tokamaks.

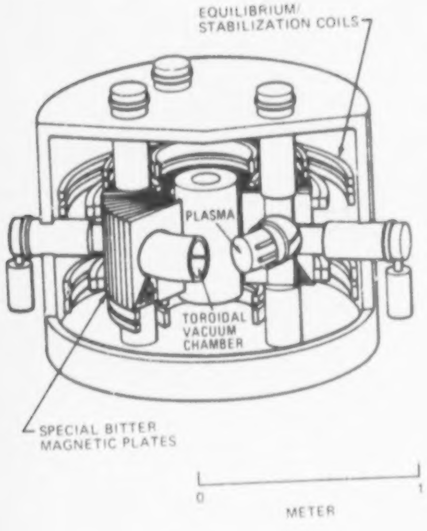


Fig. 2 Alcator C.

plasma or in a conducting fluid immersed in a magnetic field and characterized by a transverse motion of the lines of force together with the plasma. These transverse hydromagnetic waves propagate at a velocity which depends on the strength of the magnetic field and the particle density.

alpha particle: [symbol: α (alpha)] positively charged particle emitted by certain radioactive materials. It is made up of two neutrons and two protons bound together and is the nucleus of a helium atom. It is the least penetrating of the three common types of radiation (alpha, beta, gamma) emitted by radioactive material, being stopped by a sheet of paper. It is not dangerous to plants, animals, or man unless the alpha-emitting substance has entered the body. It is a by-product of the deuterium-tritium fusion reactor.

ambipolar diffusion: diffusion process in which, because of the presence of space-charge field, the electrons and ions escape to the walls at exactly the same rate. These space-charge fields are self-generated within any plasma and act to preserve a close approximation to charge neutrality.

amplifier, laser: See **laser amplifier**.

anisotropy: showing different properties as to velocity of light transmission, conductivity of heat or electricity, compressibility, etc., in different directions.

Antares: 100- to 200-kJ CO_2 laser target irradiation system at Los Alamos scheduled for completion in October 1982. [Figs. 3–7]

aperture, clear: [abbreviation: C.A., also referred to as "free aperture" or "objective aperture"] the opening in the mount of an optical system or its components that restricts the extent of the bundle of rays incident on the given surface. It is usually circular and specified by its diameter.

arc: electric discharge between two electrodes.

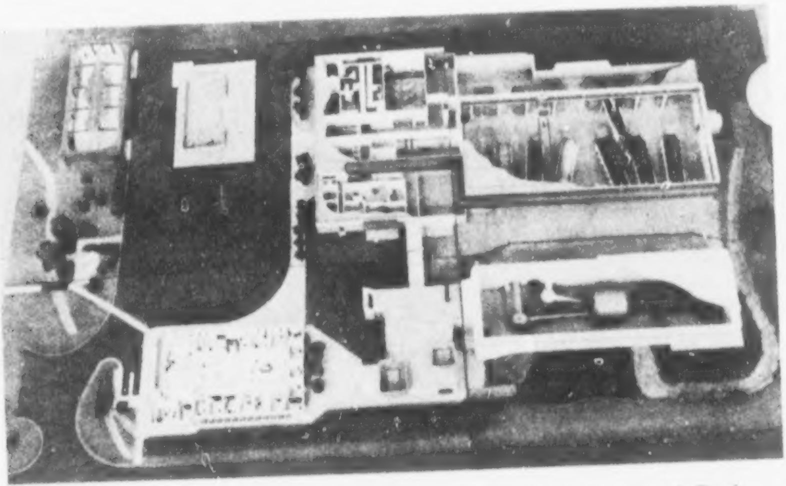


Fig. 3 Model of Antares with original 6-amplifier concept. Amplifiers 2 and 5 are shown in Fig. 4.

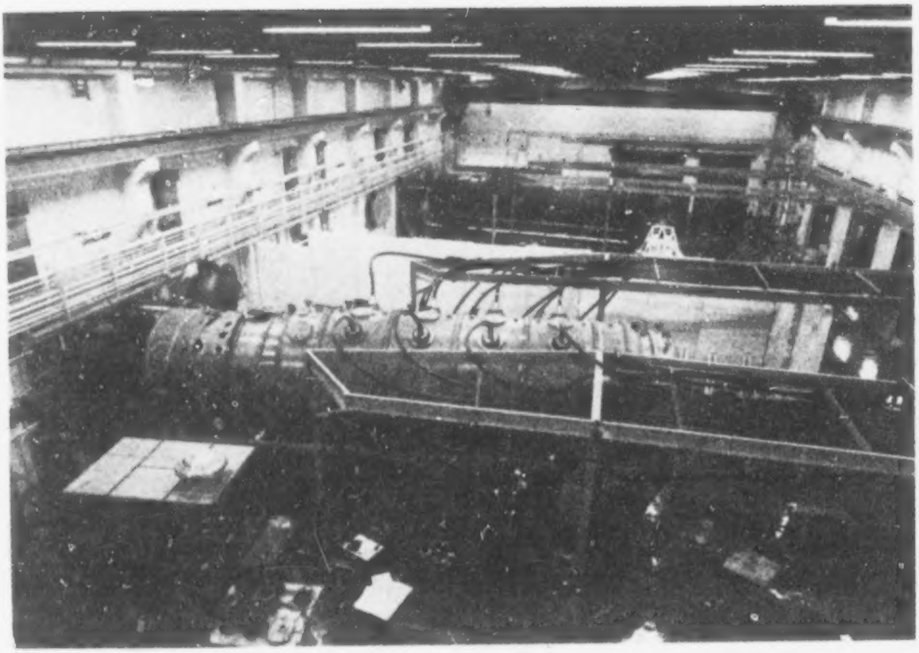
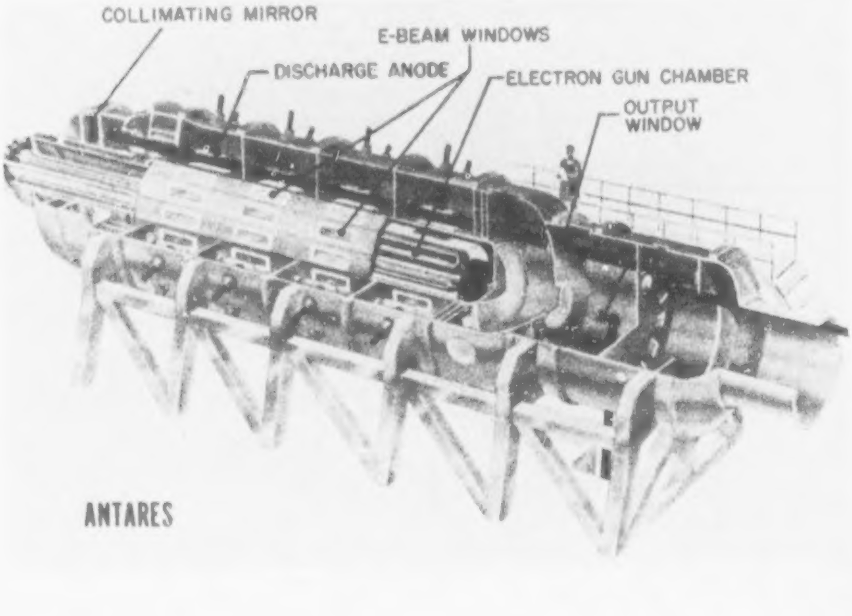


Fig. 4 Antares laser hall with two power amplifiers in place. An electron gun is being tested in the amplifier in foreground. The other amplifier is being used for optical alignment until Antares is ready for total operation in 1983.



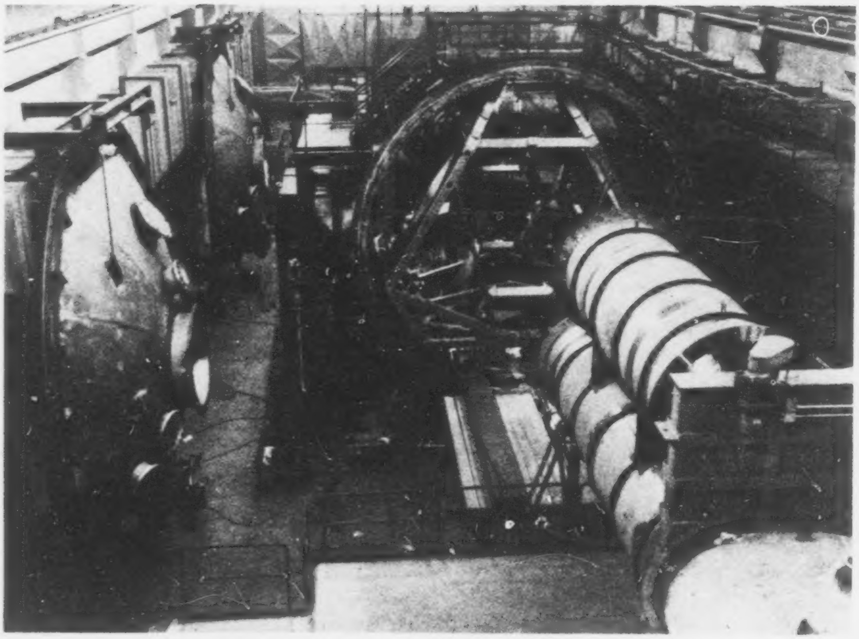


Fig. 6 Antares target chamber with end domes on left wall and spaceframe (target and mirror holder) inside. Tube in the foreground carries beam from power amplifier.

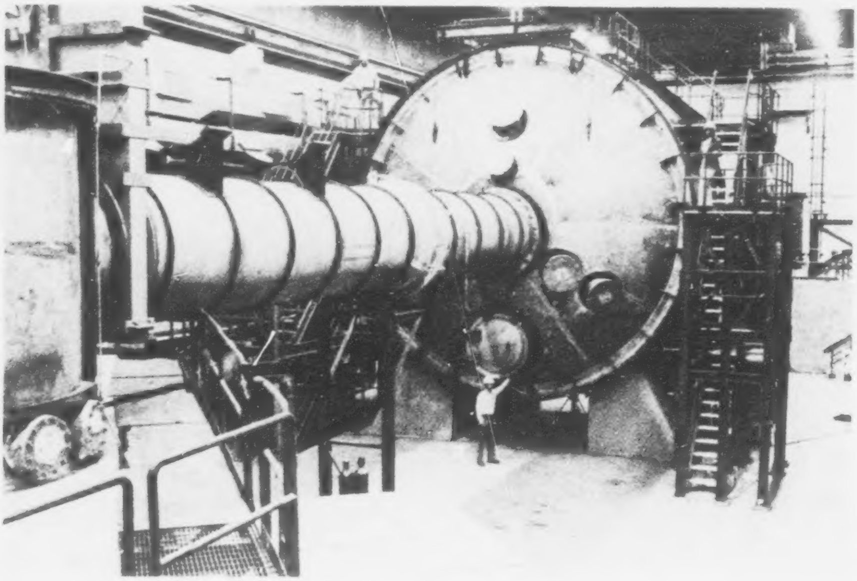


Fig. 7 Target chamber as assembled.

Argus: two-beam Nd-glass laser system at Lawrence Livermore National Laboratory to be used in target irradiation experiments. The system combines design information gained from experience with the Cyclops developmental chain and Janus irradiation experiments. [Fig. 8]

aspect ratio: the aspect ratio of a toroidally confined plasma, e.g., is the ratio of the radius of the torus to the plasma radius. [Fig. 9]

atom: particle of matter indivisible by chemical means. It is the fundamental building block of the chemical elements. The elements, such as iron, lead, and sulfur, differ from each other because they contain different kinds of atoms. There are about six sextillion (6 followed by 21 zeros, or 6×10^{21}) atoms in an ordinary drop of water. An atom contains a dense inner core (the nucleus) and a much less dense outer domain consisting of electrons in motion around the nucleus. Atoms are electrically neutral.

atomic mass: See **atomic weight**.

atomic number (Z value): number corresponding to the number of protons in the nucleus (or, in a neutral atom, to the number of external electrons). It is thus an integer expressing the nuclear charge in units of the electronic charge.

atomic weight: mass of an atom relative to other atoms. Present-day basis of the scale of atomic weights is carbon, the commonest isotope of this element arbitrarily assigned an atomic weight of 12. The unit of the scale is $^1/_{12}$ the weight of the carbon-12 atom, or roughly the mass of one proton or one neutron. The atomic weight of any element is approximately equal to the total number of protons and neutrons in its nucleus.

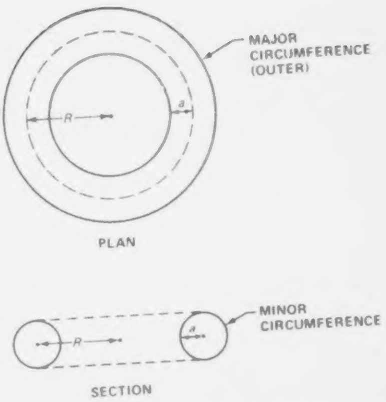


Fig. 9 The major radius of a torus is R, and the minor radius is a; the aspect ratio is R/a.

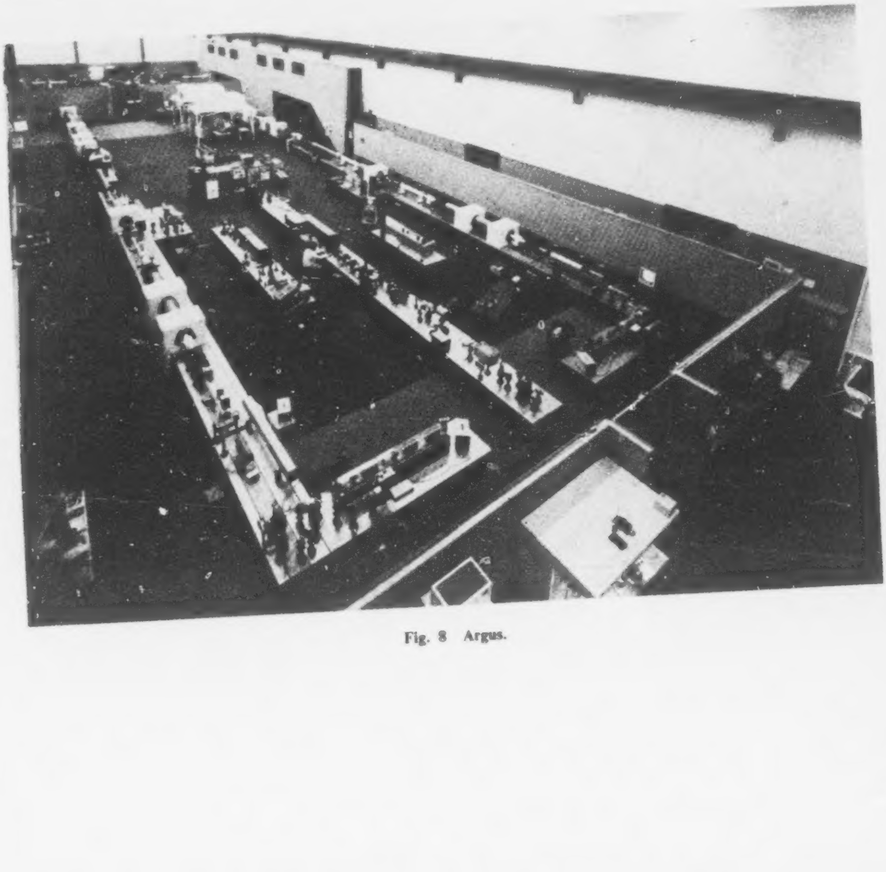


Fig. 8 Argus.

Auger effect: the radiationless transition of an electron in an atom from a discrete electronic level to an ionized continuous level of the same energy; also known as autoionization.

backscattering: the deflection of radiation or nuclear particles by scattering processes through angles greater than 90° with respect to the original direction of travel.

ballooning instability: a mode which is localized in regions of unfavorable magnetic field curvature and which becomes unstable when the plasma pressure force ∇p exceeds the mean magnetic stress $\nabla B^2/8\pi$.

banana orbit: a particular orbit with a banana shape that charged particles can follow in a toroidal magnetic field. [Fig. 10]

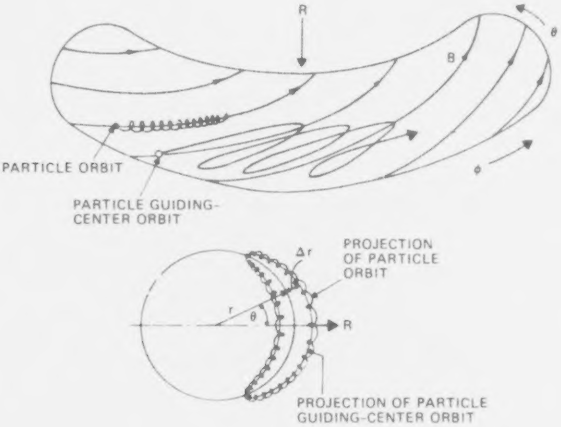

R
θ
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Fig. 10 Trapped particle orbits in a tokamak.

barn: [symbol: b] unit area used in expressing the cross sections of atoms, nuclei, electrons, and other particles. One barn is equal to 10^{-24} square centimeter. (See **cross section**.)

beam: stream of particles or electromagnetic radiation going in a single direction.

beam dump: a mass of shielding material which absorbs the energy of a particle beam.

beam hole: a hole through a reactor for passage of a beam of radiation or particles for experimental purposes.

beam splitter: optical device for dividing a radiation beam into two or more separate beams.

bellows: mechanical structure with walls like those of an accordion.

Bernstein mode: a mode which propagates perpendicular to the equilibrium magnetic field in a hot plasma. The waves are polarized with their electric field vector almost parallel to the wave vector and are hence nearly longitudinal waves. The modes propagate in frequency ranges lying between integer harmonics of the electron cyclotron frequency.

Beta-II device: magnetic mirror configuration at LLL that employs baseball seam magnet coils; formerly known as 2XIIB. [Fig. 11]

beta particle: [symbol: β (beta)] elementary particle emitted from a nucleus during radioactive decay, with a single electrical charge and a mass equal to $^1/_{1837}$ that of a proton. Negatively charged beta particle is identical to an electron; positively charged beta particle is called a positron. Beta radiation may cause skin burns, and beta emitters are harmful if they enter the body. Beta particles are easily stopped by a thin sheet of metal, however.

beta value: ratio of the outward pressure exerted by the plasma to the inward pressure which the magnetic confining field is capable of exerting. Equivalent to the ratio of particle energy density to magnetic field energy density.

blanket: region surrounding a fusion reactor core within which fusion neutrons are slowed down, heat is transferred to a primary coolant, and tritium is bred from lithium. In hybrid applications, fertile materials (U-238 or Th-232) are located in the blanket for fissile-fuel breeding purposes. [Fig. 12]

Blascon device: a conceptual spherical configuration using swirling lithium to create a vortex for injection of fusion fuel for laser ignition. [Fig. 13]

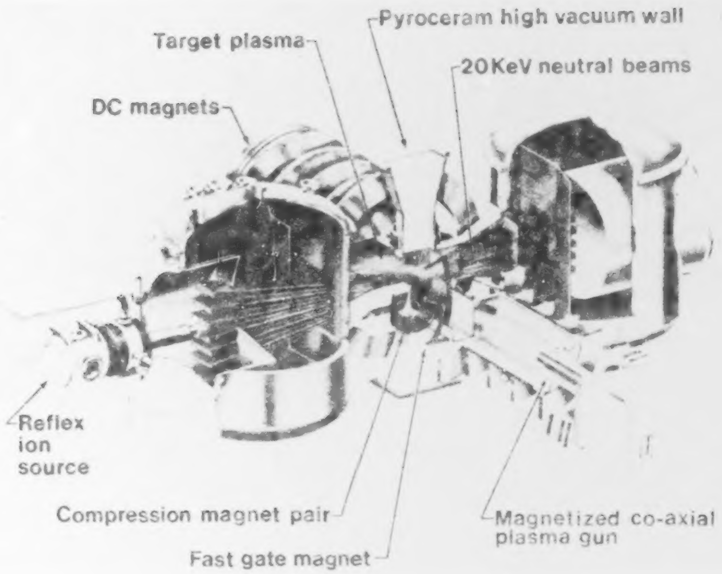


Fig. 11 Beta-II device.

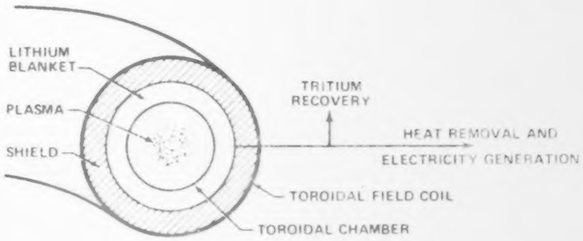


Fig. 12 Section through a torus to indicate the basic principles of a tokamak fusion reactor. (The plasma is assumed to have a circular cross section, although an elongated form may prove advantageous.)

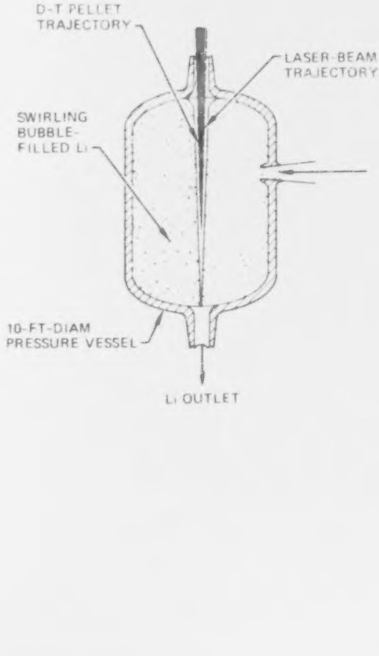


Fig. 13 Blascon-ICF liquid metal chamber.

Bohm diffusion: rapid loss of plasma across magnetic field lines caused by microinstabilities; also called "Bohm loss rate."

Boltzmann–Vlasov equation: equation that governs a high-temperature plasma in which the collisional mean free path is much larger than all the characteristic lengths of the system.

breakeven: See **Lawson criterion**.

bremsstrahlung: radiation emitted as a result of deflection (e.g., through near collisions) of rapidly moving charged particles.

Brewster angle: the polarizing angle of a dielectric is that angle of incidence for which a wave polarized parallel to the plane of incidence is wholly transmitted (no reflection). An unpolarized wave incident at this angle is therefore resolved into a transmitted partly polarized component and a reflected completely polarized component.

bundle divertor: a toroidal, longitudinal, or bundle divertor which extracts a bundle of toroidal flux to form a separatrix in the toroidal field. [Fig. 14]

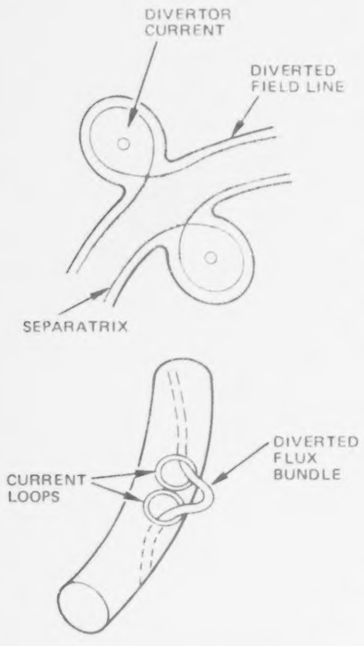


Fig. 14 Bundle divertors.

burnout: term applied to rapid reduction in density of neutral particles in a discharge, as a result of their being ionized more rapidly than they are formed.

by-product material: any radioactive material (except source material or fissionable material) obtained during production or use of source material or fissionable material; includes fission products and many other radioisotopes produced in nuclear reactors.

calorimeter: any of the several instruments used to measure the laser or particle beam energies.

Carnot efficiency: best possible efficiency of doing useful work (e.g., making electricity using a thermal cycle).

centering force: mutual attraction of all toroidal field coils toward the device centerline.

charge exchange: process in which there is a transfer of charge between two bodies during a collision between them (e.g., the collisional transfer of an electron from a neutral atom to a singly charged positive ion, the latter becoming neutral and the former charged).

classical confinement: best possible limiting case for plasma containment. Only rare collisions between particles are considered as the agent that can lead to cross field losses. It is also referred to as "classical diffusion."

coherent radiation: radiation in which the phase between any two points in the radiation field has a constant difference or is exactly the same throughout the duration of the radiation.

cold plasma: model of plasma in which the temperature is neglected with respect to the effects of interest.

collision: close approach of two or more particles, photons, atoms or nuclei, during which such quantities as energy, momentum, and charge may be exchanged.

collisionless plasma: model of plasma in which the density is so low or temperature so high that close binary collisions have practically no significance because the time scales of interest are smaller than the collision time.

confinement, classical: See **classical confinement**.

confinement, electrostatic: See **electrostatic confinement**.

confinement, inertial: See **inertial confinement**.

confinement, magnetic: See **magnetic confinement**.

containment vessel: gas-tight shell or other enclosure around a reactor.

controlled-thermonuclear fusion: process in which very light nuclei, heated to a high temperature in a confined region, undergo fusion reactions under controlled conditions, with the associated release of energy which may be harnessed for useful purposes.

coolant: substance circulated through a nuclear reactor to remove or transfer heat. Common coolants are water, air, carbon dioxide, liquid sodium, and sodium potassium alloy (NaK).

coulomb collision: collision between two charged particles. Interaction of their electric fields results in deflection of each of the particles from its initial path.

coulomb force: force of repulsion (or attraction) exerted by one electrically charged body upon another; also called "electrostatic force."

coulomb ionization: the ionization produced by coulomb forces between a projectile and target.

cross section: [symbol: σ (sigma)] a measure of the probability that a nuclear reaction will occur. Usually measured in barns, it is the apparent (or effective) area presented by a target nucleus (or particle) to an on-coming particle or other nuclear radiation, such as a photon of gamma radiation.

cross section (for a given event): quantity proportional to the probability that such an event will occur.

CTX facility: a LASL facility to investigate the production, equilibrium, stability, and confinement properties of compact toroids of the spheromak type in the absence of externally supported toroidal fields. The facility has a 4.5-m long, 1.5-m diameter vacuum chamber fitted with DC coils capable of providing a 10-kG uniform magnetic field. Two hundred forty kJ's of fast capacitor bank energy and 1 MJ of slow bank energy are available for the coaxial source and auxiliary pulsed magnetic field coils. [Figs. 15, 16]

curie: [symbol: Ci] basic unit to describe the intensity of radioactivity in a sample of material; equal to 37 billion disintegrations per second, which is approximately the rate of decay of 1 gram of radium; also a quantity of any nuclide having 1 curie of radioactivity. Named for Marie and Pierre Curie, who discovered radium in 1898.

current density: the current per unit cross-sectional area of the plasma column; also known as the electric current density.

cusped geometry: magnetic configuration in the form of cusps, such that the lines of magnetic force are everywhere convex toward the center of the configuration. Such a configuration is of particular interest for the confinement of plasma, since it is theoretically stable against the development of hydromagnetic instabilities. [Fig. 17]

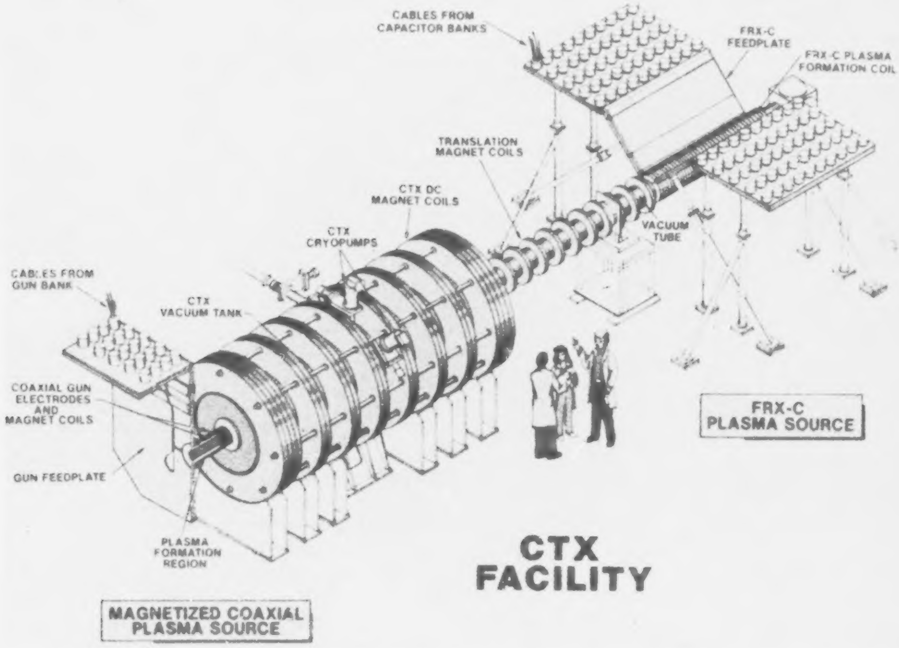


Fig. 15 CTX facility.

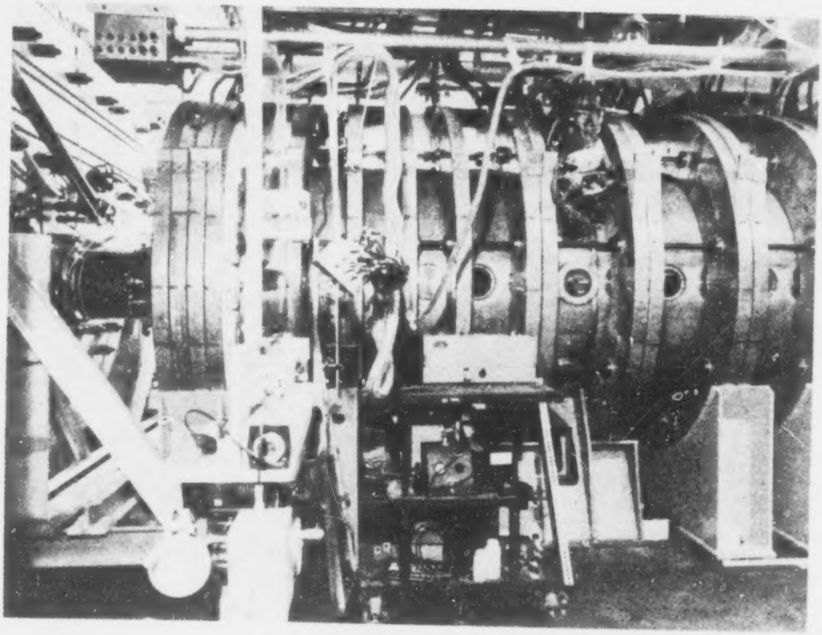


Fig. 16 CTX vacuum chamber with magnet coils and with magnetized coaxial plasma source at left.

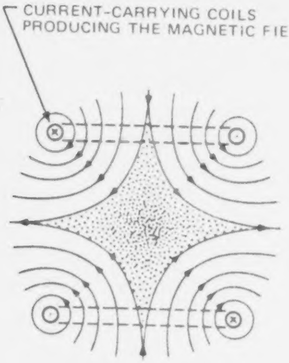


Fig. 17 Cusped geometry with ⊗ indicating current into paper and ⊙ indicating current out of paper.

Cyclops: single-chain, Nd-glass laser system at Lawrence Livermore National Laboratory for basic studies.

cyclotron frequency: natural frequency of gyration of a charged particle in a magnetic field; often and incorrectly called the Larmor frequency. (Gyration frequency is twice the Larmor frequency of precession of an orbiting electron in a magnetic field.)

cyclotron radiation: radiation emitted by charged particles in a magnetic field as a result of their natural gyration in that field. Particle gyrations are at the cyclotron frequency. Sometimes called synchrotron radiation, especially for very fast particles.

cyclotron resonance: resonance absorption of energy from an alternating-current electric field by electrons in a uniform magnetic field when the frequency of the electric field equals the cyclotron frequency.

cyclotron resonance heating: mode of heating of a plasma by resonant absorption of energy based on the waves induced in the plasma at the cyclotron frequency of ions or electrons or at a harmonic frequency of the former.

data acquisition system: system for converting data to machine-readable form and gathering it into a computer store.

Debye length: a characteristic length in a plasma, corresponding to the distance over which an electron will be influenced by the electric field of a given positive ion. In effect, it is a measure of the distance over which the electron charge density can differ significantly from the ion charge density.

decay, radioactive: See **radioactive decay**.

degenerate configuration: configuration in which the magnetic lines of force close exactly on themselves after passing around the configuration a finite number of times.

dense plasma focus: a device that basically consists of two cylindrical electrodes in a coaxial configuration and a capacitor bank. Plasma densities upon discharging of up to 10^{26} m^{-3} have been reported. [Fig. 18]

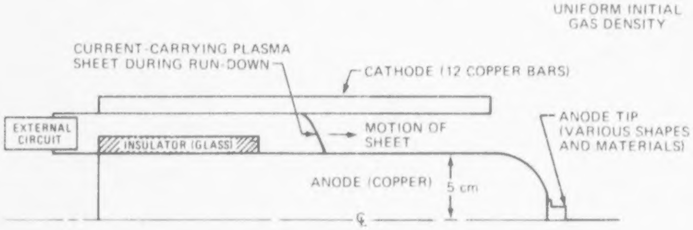

UNIFORM INITIAL GAS DENSITY
CURRENT-CARRYING PLASMA SHEET DURING RUN-DOWN
CATHODE (12 COPPER BARS)
EXTERNAL CIRCUIT
INSULATOR (GLASS)
MOTION OF SHEET
ANODE TIP (VARIOUS SHAPES AND MATERIALS)
ANODE (COPPER)
5 cm
℄

Fig. 18 LLNL plasma focus device.

detonation wave: a shock wave that accompanies detonation and has a shock front followed by a region of decreasing pressure in which the reaction occurs.

deuterium atom: an isotope of the hydrogen atom with one proton and one neutron in its nucleus and a single orbital electron.

deuteron: nucleus of a deuterium atom or the ion of deuterium.

diagnostics: procedure of determining (diagnosing) by one means or another exactly what is happening inside an experimental device during an experiment; also refers to the instruments used for diagnosing.

diamagnetic effect: the reduction of magnetic field intensity as a result of generation of circulating currents within the system.

diffusion: interpenetration of one substance into another as a result of thermal motion of the individual particles (e.g., diffusion of a plasma across a magnetic field as a result of collisions).

direct conversion: generation of electricity by direct recovery of the kinetic energy of the charged fusion reaction products. [Fig. 19]

dispersion relation: a relation between the radian frequency and the wave vector of a wave motion or instability in a plasma.

dissociative recombination: the combination of an electron with a positive molecular ion in a gas followed by dissociation of the molecule in which the resulting atom carries off the excess energy.

distribution function: density function or number of particles per unit volume of phase space; a function of the three space coordinates and the three velocity coordinates. A point in phase space represents a given position in ordinary space and a given velocity in velocity space. Therefore, the distribution function evaluated at such a point is the number or average density of particles per cubic length and cubic velocity that have the same position and velocity which is represented by the point. In reality one never counts the exact number of particles in a unit volume, thus the distribution function merely represents the average density of particles over a period of time or the most

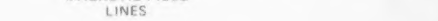


Fig. 19 A four-stage, space-charge-dominated, slab converter for a fusion-reactor output. A magnetic expander (not shown in detail) spreads the beam into a fan-shaped slab. A kink in the directing magnetic field siphons off most of the electrons, only slightly perturbing the ion trajectories. A negative electrode turns back the remaining electrons. Space charge then blows up the ion beam, spreading it over the collecting electrodes. Voltages on the different collecting stages would be adjusted for optimum power output, depending on the ion energy distribution.

"probable" distribution of particles at a particular time.

DITE: Divertor and Injection Tokamak Experiment at Culham Laboratory in UK will make an extensive study of (i) neutral injection heating in tokamaks and (ii) the control of impurities and recycling using a bundle divertor.

divertor: component of a toroidal fusion device that serves to divert charged particles in the outer shell of the discharge into a separate chamber where they strike a barrier, become neutralized, and are pumped away. In this way, energetic particles in the outer shell are prevented from striking the walls of the main discharge chamber and releasing secondary particles that would cool the discharge.

Doppler broadening: frequency spreading that occurs in single-frequency radiation when the radiating atoms, molecules, or nuclei do not all have the same velocity and may each give rise to a different Doppler shift.

Doppler effect: the change in the observed frequency of a wave due to relative motion of source and observer.

Doppler shift: the amount of the change in the observed frequency of a wave due to the Doppler effect; sometimes called Doppler frequency.

Doublet devices: noncircular cross-section tokamak devices with a kidney-shaped cross section. [Fig. 20]

drift surface: surface on which the guiding center of a particle is constrained to move under the laws of adiabatic invariance.

drift waves: oscillations in a magnetically confined plasma which arise in the presence of density gradients (e.g., at the plasma's surface) and which resemble the waves that propagate at the interface of two fluids of different density in a gravity field.

duty factor: ratio of the plasma burn time to the time for a complete cycle in a fusion system.

dye laser: a type of tunable laser in which the active material is a dye, such as acridine red or esculin, with very large molecules, and laser action takes place between the first excited and ground electronic states, each of which comprises a broad vibrational-rotational continuum.

EBT: a magnetic fusion concept in which high-beta electron rings produced by microwave heating stabilizes a bumpy torus. [Figs. 21, 22]

EBT-S: Elmo Bumpy Torus is a 24-sector toroidal magnetic trap at Oak Ridge National Laboratory that uses microwave heating to produce and maintain a steady-state hot plasma.

echoes: a wave packet that has been reflected or otherwise returned with sufficient delay and magnitude to be perceived as a signal distinct from that directly transmitted.

E-coil: the plasma current-driving or ohmic-heating coil in a Doublet device. Ideally, the

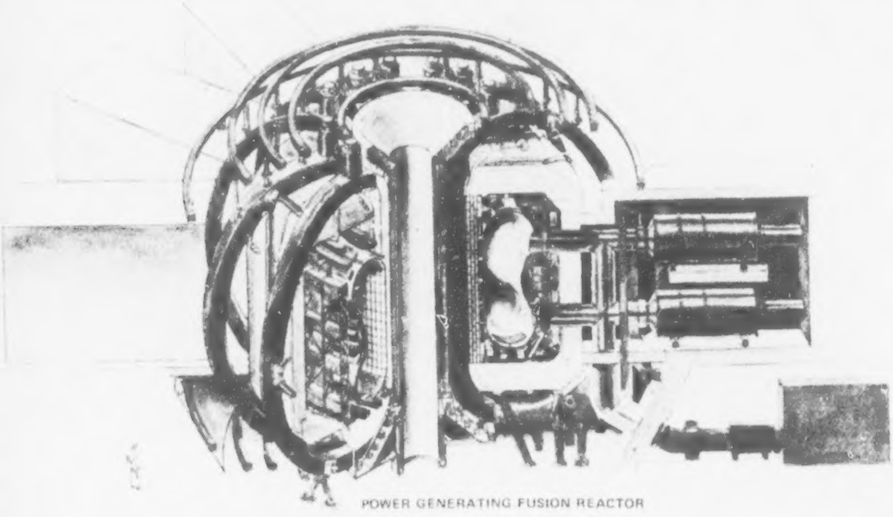


Fig. 20 Doublet device.

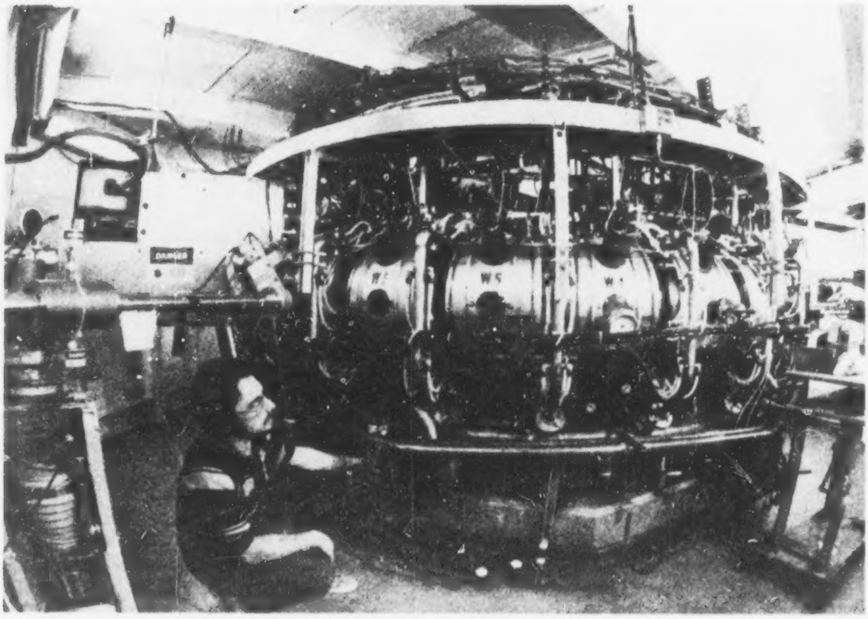


Fig. 21 Elmo Bumpy Torus.

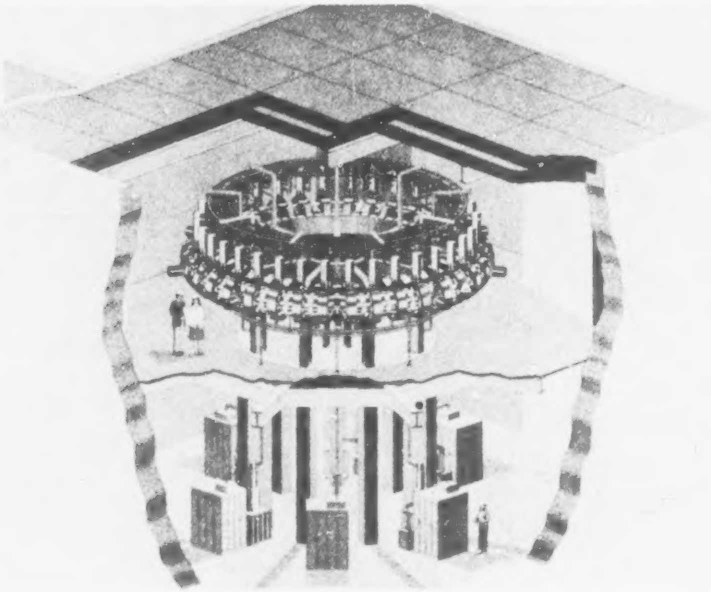


Fig. 22 EBT–Proof of Principle.

E-coil makes no magnetic field in the confinement system.

ECRH: Electron Cyclotron Resonance Heating in which only electrons gain energy by action of an applied RF field operating at the electron cyclotron frequency.

eddy current: an electric current induced within the body of a conductor when that conductor either moves through a nonuniform magnetic field or is in a region where there is a change in magnetic flux.

eddy-current loss: energy loss due to undesired eddy currents circulating in a magnetic core.

effective half-life: time required for a radionuclide contained in a biological system, such as a man or an animal, to reduce its activity by half as a combined result of radioactive decay and biological elimination.

eigenfrequency: one of the frequencies at which an oscillatory system can vibrate.

eigenfunction: a solution to the Sturm Liouville partial differential equation, an eigenvector.

eikonal equation: an equation for propagation of electromagnetic or acoustic waves in a nonhomogeneous medium; it is valid only when the variation of the properties of the medium is small over the distance of a wavelength.

E-layer: cylinder of relativistic electrons which gyrate in a magnetic field and produce a self-field strong enough to dominate the external field to produce a "field reversal" condition.

electric conductivity: the ratio of the electric current density to the electric field in the material.

electric probe: a device used to measure electron temperatures, electron and ion densities, space and wall potentials, and random electron currents in a plasma; consists substantially of one or two small collecting electrodes to which various potentials are applied, with the corresponding collection currents being measured.

electromagnetic radiation: radiation consisting of associated and interacting electric and magnetic waves that travel at the speed of light. Examples: light, radio waves, gamma rays, X rays. All can be transmitted through a vacuum. (Compare **ionizing radiation.**)

electron: [symbol: e^-] elementary particle with a unit negative electrical charge and a mass $^1/_{1837}$ that of the proton. Electrons surround the positively charged nucleus and determine the chemical properties of the atom. Positive electrons, or positrons, also exist.

Electron Beam Fusion Accelerator: an electron beam accelerator at Sandia to be used for inertial confinement fusion.

electron cyclotron wave: See **whistler.**

electron density: the number of electrons in a unit volume.

electron temperature: the temperature at which ideal gas molecules would have an average kinetic energy equal to that of electrons in a plasma under consideration.

electron volt (eV): unit of energy equal to the energy acquired by a singly charged particle in passing through a potential difference of one volt. $1\ \mathrm{eV} = 1.6 \times 10^{-19}$ joule.

electrostatic analyzer: a device which filters an electron beam, permitting only electrons within a very narrow range to pass.

electrostatic confinement: use of electric fields to contain a plasma.

electrostatic probes: See **electric probe.**

electrostatic waves: longitudinal waves appearing in a plasma owing to a perturbation of electric neutrality. In the case of a cold unmagnetized plasma, and also for large wavelengths, the frequency of these waves is, by definition, equal to the plasma frequency.

element: one of the 103 known chemical substances that cannot be divided into simpler substances by chemical means. A substance whose atoms all have the same atomic number. Examples: hydrogen, lead, uranium.

Elmo Bumpy Torus: See **EBT.**

energy balance: comparison of the energy put into a system (e.g., a hot plasma) and the energy dissipation from the system by one mechanism or another (e.g., by an increase in the plasma temperature, by radiation, or by various mechanisms of particle loss from the plasma).

energy replacement time: time required for a plasma to lose (via radiation or other loss mechanisms) an amount of energy equal to its average kinetic energy.

equations of motion: a set of hydrodynamical equations representing the application of Newton's second law of motion to a fluid system; the total acceleration of an individual particle is equated to the sum of the forces acting on the particle within the fluid.

equilibrium field windings: See **field shaping coils.**

ETF tokamak: Engineering Test Facility tokamak.

excitation radiation: radiation of line spectra as a result of the excitation of excited states (e.g., through inelastic collisions of electrons with ions) and the subsequent de-excitation of these states by radiative transitions.

Fabry–Perot interferometer: an interferometer having two parallel glass plates (whose separation of a few centimeters may be varied), silvered on their inner surfaces so that the incoming wave is multiply reflected between them and ultimately transmitted.

Faraday rotator: used to isolate (protect) a laser amplifier chain against back reflection from the target. It does this by rotating the plane of polarization of the optical pulse 90° for a round trip pass. With this polarization the optical pulse is rejected by a suitably placed polarizer. Consists of a circular glass disk suitably doped with a magnetic ion and placed in the magnetic field of a surrounding solenoid.

fast neutron: neutron with energy greater than approximately 100,000 electron volts.

fertile material: nuclide that will convert to fissile material on neutron capture and radioactive decay (e.g., uranium-238 or thorium-232).

field shaping coils: a set of poloidal field windings in a tokamak which provides a magnetic field topology designed to constrain horizontal and vertical motion of the plasma as well as, in some applications, to produce a noncircular plasma cross section or a divertor separatrix. [Fig. 23]

namely: any material fissionable by neutrons of all energies, especially including thermal (slow) neutrons as well as fast neutrons; for example, uranium-235 and plutonium-239.

fission: splitting of a heavy nucleus into two approximately equal parts (which are nuclei of lighter elements), accompanied by the release of a relatively large amount of energy and generally one or more neutrons. Fission can occur spontaneously but usually is caused by nuclear absorption of gamma rays, neutrons or other particles.

Flibe: a molten salt of fluorine, lithium, and beryllium.

flute instability: See **interchange instability.**

flux (neutron): measure of the intensity of neutron radiation; number of neutrons passing through 1 square centimeter of a given target in 1 second. Expressed as nu, where n = the number of neutrons per cubic centimeter and u = their velocity in centimeters per second. (See **integrated neutron flux**.)

FMIT facility: Fusion Materials Irradiation Test facility.

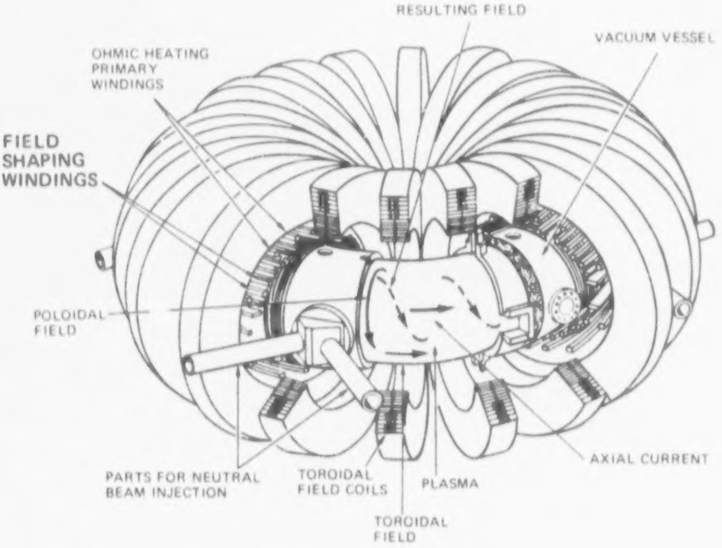


Fig. 23 Basic components of the tokamak.

first wall: first physical boundary that surrounds a plasma.

fissile material: while sometimes used as a synonym for fissionable material, this term has also acquired a more restricted meaning,

f-number: denotes the ratio of the equivalent focal length of an objective to the diameter of its entrance pupil.

Fokker–Planck equation: equation that describes the motion of a free particle in velocity space and which is applicable to plasmas when the cumulative effect of weak deflections resulting from relatively distant encounters is more important than the effect of occasional large deflections.

frozen-in magnetic field: expression for the fact that the movement of a fluid of infinite conductivity in the presence of a magnetic field is accompanied by a deformation of the field, as if the lines of force were frozen within the fluid and carried along with it.

fusion: merging of two light atomic nuclei into a heavier nucleus, accompanied in general by the release of energy.

fusion, controlled thermonuclear: See **controlled thermonuclear fusion.**

fusion-fission hybrid: reactor in which energy is produced by both fusion and fission reactions. Fusion neutron source is typically surrounded by a subcritical blanket containing fissile material. If fertile material is also contained in the blanket, the reactor will produce additional fissile material.

gain (or amplification): increase in a signal transmitted from one point to another through an amplifier.

gamma rays: [symbol: γ (gamma)] high-energy, short-wavelength electromagnetic radiation. Gamma radiation frequently accompanies alpha and beta emissions and always accompanies fission. Gamma rays are very penetrating and are best stopped or shielded against by dense materials, such as lead or depleted uranium. Gamma rays are essentially similar to X rays but are usually more energetic and are nuclear in origin. (Compare **X ray**; see **radioactive decay**.)

gas blanket: a cold, dense volume of gas surrounding a hot plasma and used to protect a material wall from bombardment by hot ions (with subsequent sputtering and impurity production).

getters: materials that can be used for the purification of vacuum atmospheres.

guiding center: instantaneous center of rotation of a charged particle in motion in a sufficiently strong magnetic field and subject to other effects (electric field, for example).

gyrotron: a device for producing microwave energy that utilizes a strong axial magnetic field in a cavity resonator to produce azimuthal bunching of an electron beam.

half-life: time in which half the atoms of a particular radioactive substance disintegrate to another nuclear form. Measured half-lives vary from millionths of a second to billions of years. (See **radioactive decay**.)

half-life, effective: See **effective half-life**.

Hall effect: the development of a transverse electric field in a current-carrying conductor placed in a magnetic field.

Hamiltonian function: a function of the generalized coordinates and momenta of a system, equal in value to the sum over the coordinates of the product of the generalized momentum corresponding to the coordinate and the coordinate's time derivative minus the Lagrangian of the system; it is numerically equal to the total energy in the Lagrangian and does not depend on time explicitly; the equations of motion of the system are determined by the functional dependence of the Hamiltonian on the generalized coordinates and momenta.

hard-core pinch device: pinch-discharge device that incorporates solid central conductor. The discharge occurs in an annular region about this conductor.

Hartree–Fock approximation: a refinement of the Hartree method in which one uses determinants of single-particle wave functions rather than products, thereby introducing exchange terms into the Hamiltonian.

Hartree method: an iterative variational method of finding an approximate wave function for a system of many electrons, in which one attempts to find a product of single-particle wave functions, each of which is a solution of the Schroedinger equation with the field deduced from the charge density distribution due to all the other electrons; also known as self-consistent field method.

heat exchanger: device that transfers heat from one fluid (liquid or gas) to another or to the environment.

heavy hydrogen: deuterium.

heavy water: [symbol: D_2O] water containing significantly more than the natural proportion (one in 6500) of heavy hydrogen (deuterium) atoms to ordinary hydrogen atoms; used as a moderator in some reactors because it slows down neutrons effectively and also has a low cross section for absorption of neutrons.

Helios facility: a 10-kJ, 8-beam, carbon dioxide laser facility at Los Alamos for laser fusion experiments. [Figs. 24, 25]

hertz: unit of frequency equivalent to one cycle per second.

high-beta plasma: a plasma in which the beta value is typically 0.1 to 1.

high-frequency heating: heating by means of rf current produced by an electron tube oscillator or an equivalent rf power source. [Fig. 26]

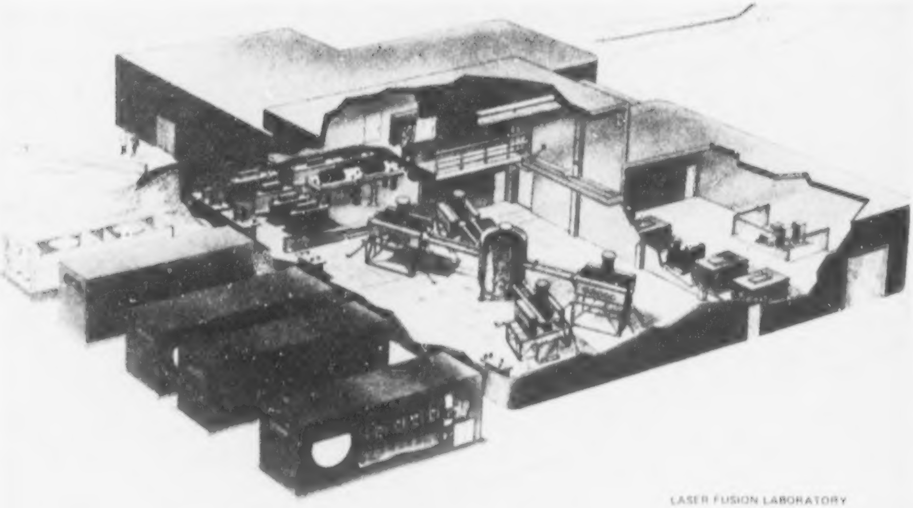


Fig. 24 Artist's concept of Helios laser system.

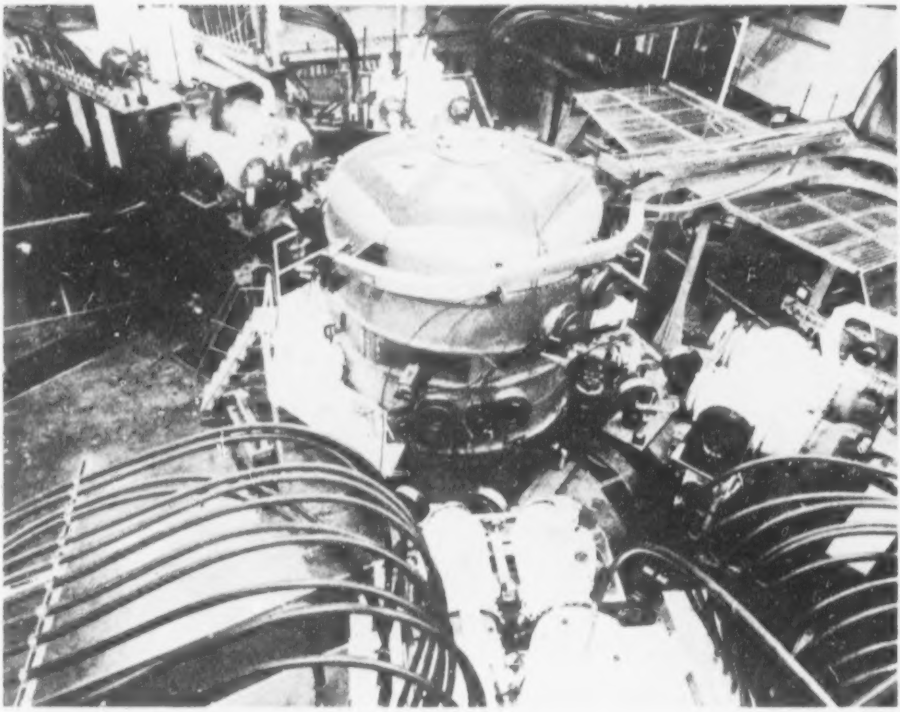


Fig. 25 Helios target chamber in center with amplifiers at top center and left and at bottom center and right.

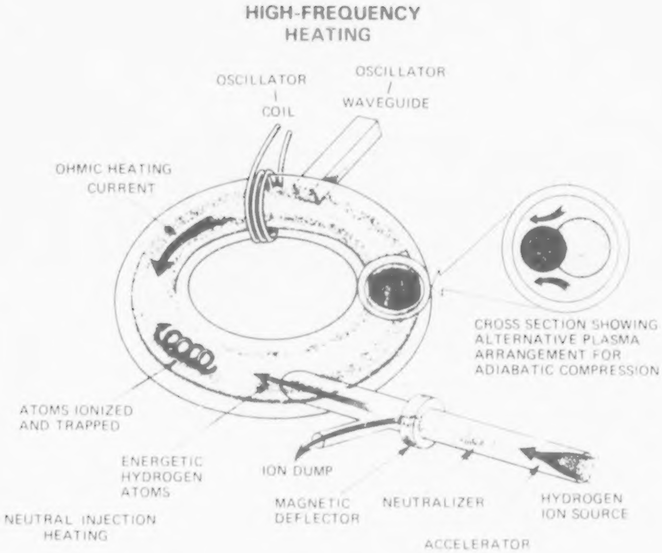


Fig. 26 Main heating systems for tokamaks.

holography: a technique for recording and later reconstructing the amplitude and phase distribution of a wave disturbance.

homopolar generator: a direct-current generator in which the poles presented to the armature are all of the same polarity, so that the voltage generated in active conductors has the same polarity at all times; a pure direct current is thus produced without commutation.

hot cells: heavily shielded enclosure in which radioactive materials can be handled by persons using remote manipulators and viewing the materials through shielded windows or periscopes.

hybrid reactors: See **fusion-fission hybrid**.

hybrid resonance: a resonance in a magnetized plasma which involves aspects of both parallel bunching, characterized by the plasma frequency, and perpendicular particle motion, characterized by the cyclotron frequency.

hydrogen: [symbol: H] lightest element, No. 1 in the atomic series. It has two natural isotopes of atomic weights 1 and 2. The first is ordinary hydrogen, or light hydrogen; the second is deuterium, or heavy hydrogen. A third isotope, tritium, atomic weight 3, is a radioactive form produced in reactors by bombarding lithium with neutrons.

hydrogen embrittlement: a decrease in fracture strength of metals due to the incorporation of hydrogen in the metal lattice.

hydromagnetic instability: instability arising from macroscopic motions of a conducting fluid (liquid or gas) as a result of its interaction with a magnetic field. (See **interchange instability; kink instability**).

hydromagnetics: See **magnetohydrodynamics**.

HYLIFE converter: High Yield Lithium Injection converter. [Fig. 27]

ICRH: Ion Cyclotron Resonance Heating. (See **ion cyclotron resonance heating**.)

ignition temperature: temperature at which the energy deposited in a plasma through the fusion process just equals the energy losses (e.g., through radiation processes).

impact fusion: the science associated with the acceleration of a DT-bearing projectile and subsequent impact with a stationary target or a similarly accelerated projectile.

impact fusion drivers: a class of macroparticle accelerators to be used in inertial confinement fusion.

incoherent scattering: scattering of particles or photons in which the scattering elements act independently of each other so that no definite phase relationships are among the different parts of the scattered beam.

index of refraction: ratio of the velocity of light in air to the velocity of light in a refractive material for a given wavelength.

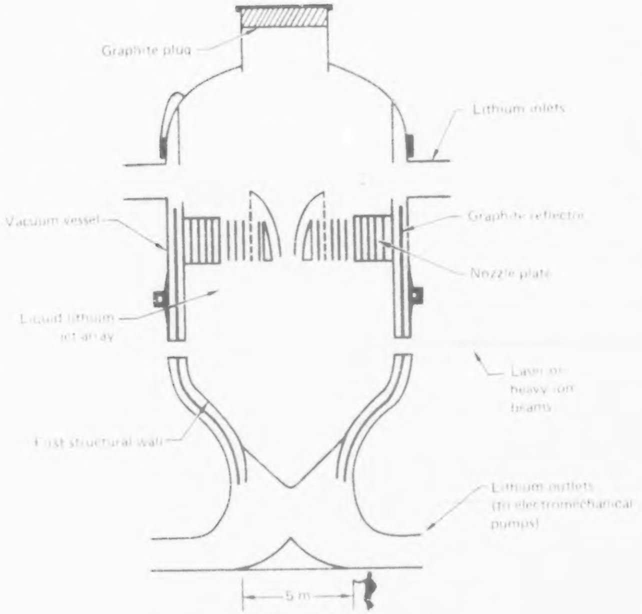


Fig. 27 Elevation cross section of HYLIFE chamber.

inertial confinement: a dynamic, nonmagnetic plasma confinement scheme that uses compressional inertial forces, i.e., laser radiation compressing a DT pellet. [Fig. 28]

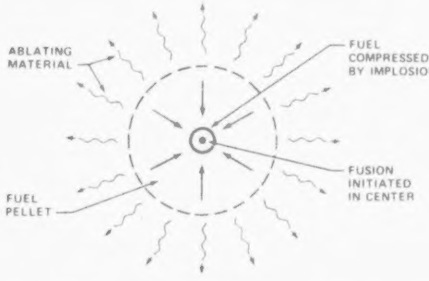


Fig. 28 Representation of compression of a fuel pellet as a result of surface ablation.

integrated neutron flux: flux multiplied by time, usually expressed as nvt, when n = the number of neutrons per cubic centimeter, v = their velocity in centimeters per second, and t = time in seconds. [See **flux (neutron)**.]

intensity: energy or the number of photons or particles of any radiation incident upon a unit area or flowing through a unit of solid material per unit of time. In connection with radioactivity, the number of atoms disintegrating per unit of time. [See **flux (neutron)**.]

interchange instability: the type of hydromagnetic instability in which the plasma interchanges position with the magnetic field; also called a "flute-type instability," since it would be expected that the interface between the plasma and the magnetic field would become fluted.

interferometer, laser: See **laser interferometer**.

interferometer, optical: See **optical interferometer**.

internal ring devices: toroidal systems in which current-carrying rings are suspended either mechanically or magnetically inside the plasma chamber parallel to the minor axis of the torus.

INTOR tokamak: **IN**ternational **TO**kamak **R**eactor, a large tokamak that is being planned and jointly funded by the U.S., the USSR, Japan, and the European community.

Ioffe bar: special form of magnetic field which, when added to a conventional magnetic mirror, provides a "magnetic well" and cures the hydromagnetic instability.

ion: atom (or molecularly bound group of atoms) which has become charged as a result of gaining or losing one or more orbital electrons. A completely ionized atom is one stripped of all its electrons.

ion acoustic wave: a longitudinal compression wave in the ion density of a plasma, which can occur at high electron temperatures and low frequencies, caused by a combination of ion inertia and electron pressure.

ion cyclotron resonance heating: heating of a plasma by resonant absorption of energy from waves induced in the plasma at or near the ion cyclotron frequency.

ionization: process of removing or adding an electron to a neutral atom, thereby creating an ion; term also often used in connection with removal of an electron from a partially ionized atom.

ionization potential: the energy per unit charge needed to remove an electron from a given kind of atom or molecule to an infinite distance.

ionizing radiation: any radiation displacing electrons from atoms or molecules, thereby producing ions. Examples: alpha, beta, gamma radiation; short-wave ultraviolet light. Ionizing radiation may cause severe skin or tissue damage.

irradiation: exposure to radiation, as in a nuclear reactor.

isotope: one of several species of the same element, possessing different numbers of neutrons (but the same number of protons) in their nuclei.

isotropic plasma: a plasma whose properties, such as pressure, are not dependent on the direction along which they are measured.

ISX tokamak: flexible, medium-size tokamak designed for easy access and rapid changing of the vacuum system and poloidal field system. [Fig. 29]

Janus: solid-state, Nd-glass laser system at Lawrence Livermore National Laboratory designed for one- and two-beam irradiation of laser-fusion targets with 100-ps pulses. [Fig. 30]

JET tokamak: Joint European Torus is a large tokamak that is commonly owned by the European Communities. It is being built at the Culham Laboratory and will be comparable to TFTR.

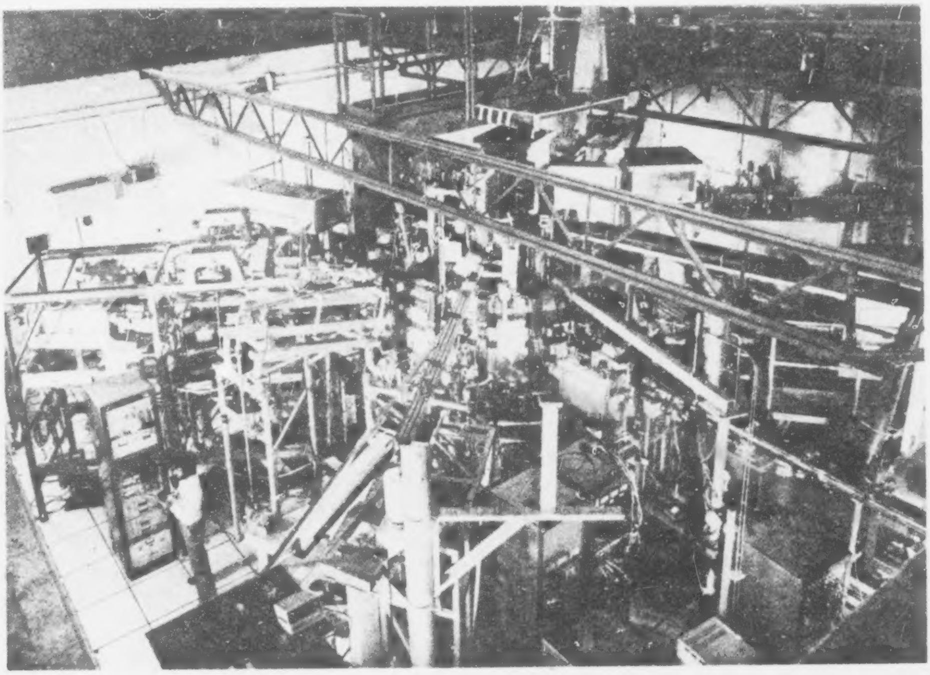


Fig. 29 ISX tokamak.

RESCREEN & SQUARE HALFTONES

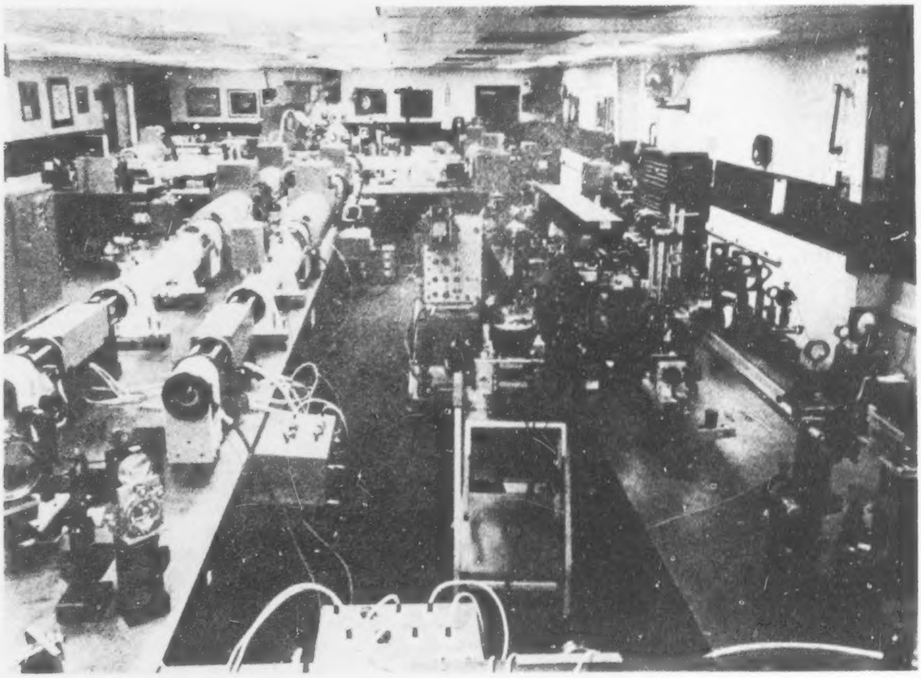


Fig. 30 Janus.

Joule heating: See **ohmic heating.**

JT-60: large Japanese tokamak whose purpose is to extend the tokamak parameters closer to reactor parameters and to investigate plasma confinement and heating and associated technological problems.

kerma: the total kinetic energy of charged particles produced by ionizing radiation per unit mass of irradiated material in ergs per gram.

kinetic pressure: density of kinetic energy due to the thermal motion of the particles composing the plasma. For particles of a given type, the kinetic pressure is equal to the product nkT, where n is the particle density, k the constant of Boltzmann, and T the absolute temperature of plasma.

kinetic temperature: measure of the energy of random motion of an assembly of particles in thermodynamic equilibrium. Specifically, temperature (T) appropriate to the Maxwellian distribution assumed by a system of particles upon equipartition of energy among the three translational degrees of freedom. The mean particle energy is then 3/2 kT, where k is Boltzmann's constant.

kinetic theory: a theory which attempts to explain the behavior of physical systems on the assumptions that the systems are composed of large numbers of atoms or molecules in vigorous motion, that energy and momentum are conserved in collisions of these particles, and that statistical methods can be applied to deduce the particles' average behavior.

kink instability: hydromagnetic instability that sometimes develops in a thin plasma column carrying a strong axial current. If a kink begins to develop in such a column the magnetic forces on the inside of the kink become larger than those on the outside, so that in general it tends to grow in magnitude. The column then becomes unstable and undergoes a gross lateral displacement toward the walls of the discharge vessel. [Fig. 31]

klystron: an evacuated electron-beam tube in which an initial velocity imparted to electrons in the beam results subsequently in density modulation of the beam; used as an amplifier in the microwave radiation.

Kruskal limit: a value of current which, if exceeded, would theoretically result in hydromagnetic instabilities in tokamaks.

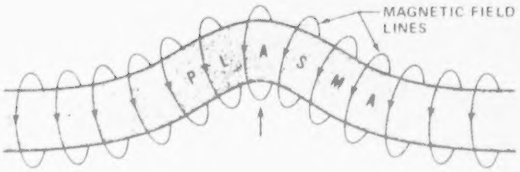


Fig. 31 The kink instability in a plasma. (The plasma is actually in the form of a spiral which is shown here in a two-dimensional representation.)

Lagrangian: the difference between the kinetic energy and the potential energy of a system of particles, expressed as a function of generalized coordinates and velocities from which Lagrangian equations can be derived.

Landau damping: damping of a wave propagating in a hot plasma, due to the interaction of the wave with the particles of the plasma whose velocity is close to the phase velocity of the wave.

Langmuir frequency: See **plasma frequency.**

Langmuir probe: a device for measuring the temperature and electron density in a plasma, consisting of an electrode in contact with the plasma whose potential is varied while the resulting collection currents are measured.

Large Coil Project: a large test facility at ORNL designed to test superconducting magnets that have possible applications in the tokamak reactor program. [Fig. 32]

Larmor radius: for a charged particle moving transversely in a uniform magnetic field, the radius of curvature of the projection of its path on a plane perpendicular to the field; also known as gyromagnetic radius.

laser amplifier: *Disk Amplifier:* this device utilizes thin disks or slabs of glass doped with the neodymium ion. These disks are placed at Brewster's angle within a cavity surrounded by a cylindrical array of flashlamps. The flashlamps are used to create the population inversion. *Rod Amplifier:* a device for amplifying coherent optical energy usually consisting of a

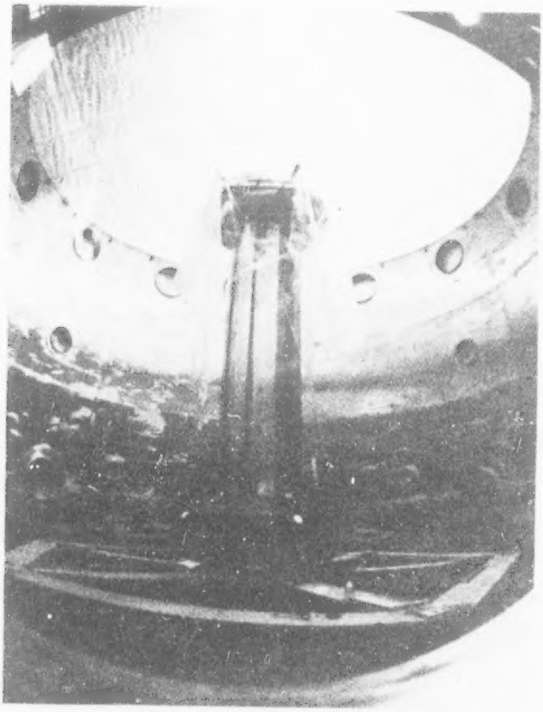


Fig. 32 Large Coil Project.

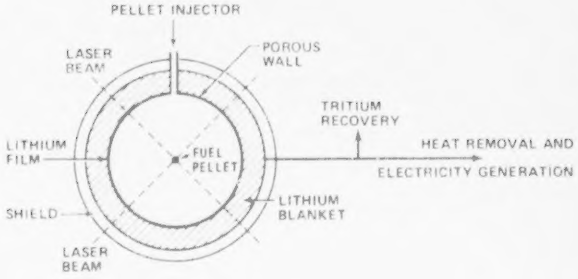


Fig. 33 A conceptual laser-fusion reactor cavity.

cylinder of glass or crystalline material suitably doped with an ionic compound to form the amplifying medium. This medium is excited (pumped) by closely coupled flashlamps to create the population inversion required for amplification.

laser fusion: nuclear fusion process that occurs when a small pellet of fuel material is compressed by a burst of laser light. (See **inertial confinement**.) [Fig. 33]

laser-heated solenoid: linear-fast-solenoid 300-kG magnet, 3 m in length which can confine a plasma heated by a 10-kJ 2-μs pulsed CO_2 laser. Purpose is to heat a hydrogen plasma at a density of 10^{18} cm^{-3} to a plasma temperature higher than one kV and to study end losses, radiation, plasma coupling, conduction losses, beam propagation,[1] and trapping. [Fig. 34]

at a temperature of about 70,000,000 degrees to produce net power in a fusion reactor.

Lenz's law: the law that states whenever there is an induced electromotive force (emf) in a conductor, it is always in such a direction that the current it would produce would oppose the change which causes the induced emf.

levitron: single-ring multipole device with an additional current-carrying rod perpendicular to the ring axis.

limiters: structures, placed in contact with the edge of a confined plasma, which are used to define the shape of the outermost magnetic flux surface. [Fig. 35]

Linus device: an experiment to demonstrate the application of magnetic flux compression by liners of sodium potassium (NaK) eutectic liquid metal alloys to the confinement and heating of high-density plasmas.

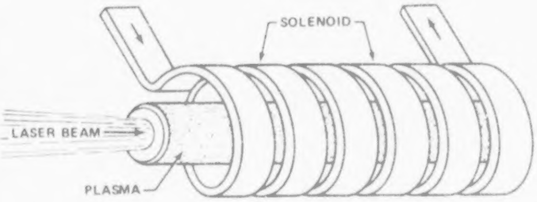


Fig. 34 Laser-heated solenoid for plasma fusion.

laser interferometer: an interferometer which uses a laser as a light source. Because of the monochromaticity and high intrinsic brilliance of laser light, it can operate with path differences in the interfering beams of hundreds of meters, in contrast to a maximum of about 20 centimeters for classical interferometers.

laser, solid-state: See **solid-state laser**.

Lawson criterion: condition that the product of number density and confinement time of a plasma must equal approximately 10^{14} cm^3-sec

Lorentz dissociation: dissociation of molecular ions by the mechanism described under **Lorentz ionization.**

Lorentz force: force exerted on an electric charge moving nonparallel to a magnetic field. This is the source of the forces exerted on conductors and windings associated with a magnetic confinement device.

Lorentz gas: hypothetical gas in which the electrons are assumed not to interact with each

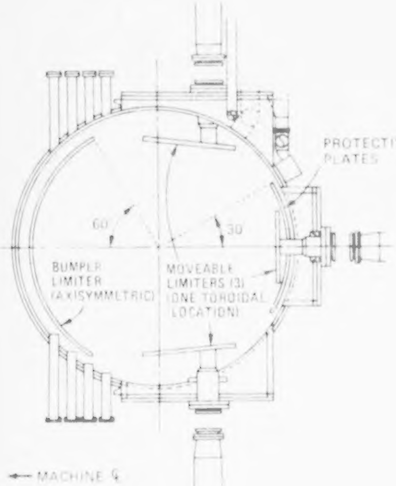

PROTECTIVE PLATES
60°
30°
BUMPER LIMITER (AXISYMMETRIC)
MOVEABLE LIMITERS (3) (ONE TOROIDAL LOCATION)
← MACHINE ℄

Fig. 35 Diagram of the limiters and protective plates in Tokamak Fusion Test Reactor. The bumper limiter covers the entire toroidal circumference. The protective plates are located in areas irradiated by the neutral beams.

other, and all the positive ions are considered to remain at rest; also called "electron gas."

Lorentz ionization: ionization of neutral atoms (taken generally at a high level of excitation) obtained by projecting them at high velocity in a strong magnetic field. Each injected atom is thus subjected to an electrical field proportional to the product of the velocity of the atom by magnetic induction.

loss cone: in the velocity space related to a magnetic mirror, the cone having an axis of symmetry parallel to the magnetic field and an apex angle alpha defined by $\sin \alpha = 1/\sqrt{R}$, R being the mirror ratio. Particles whose velocity vectors lie in the loss cone will not be reflected by the mirror.

low-beta plasma: a plasma in which the beta value is typically 0 to 0.01.

luminescence: light emission that cannot be attributed merely to the temperature of the emitting body, but results from such causes as chemical reactions at ordinary temperatures, electron bombardment, electromagnetic radiation, and electric fields.

Mach-Zehnder interferometer: a variation of the Michelson interferometer used mainly in measuring the spatial variation of the refractive index of a gas; the device has two semitransparent mirrors and two wholly reflecting mirrors at alternate corners of a rectangle, and half the beam travels along each side of the rectangle.

magnetic bottle: magnetic field used to confine a plasma in controlled fusion (thermonuclear) experiments.

magnetic confinement: use of magnetic fields to contain a plasma.

magnetic force parameter: a dimensionless number equal to the product of the square of the magnetic permeability, the square of the magnetic field strength, the electrical conductivity, and a characteristic length, divided by the product of the mass density and the fluid velocity.

magnetic Mach number: a dimensionless number equal to the ratio of the velocity of a fluid to the velocity of Alfvén waves in the fluid.

magnetic mirror: magnetic field that is generally axial with a local region of increased intensity causing convergence of the field lines. A particle moving into the region of converging magnetic field lines will be reflected if the ratio of its energy parallel and perpendicular to the magnetic field satisfies the relationship:

$$\frac{E_{\parallel}}{E_{\perp}} \leq \left(\frac{B_m - 1}{B_o}\right)$$

where B_m and B_o are the magnetic field strengths at the mirror and at the original point, respectively. [Fig. 36]

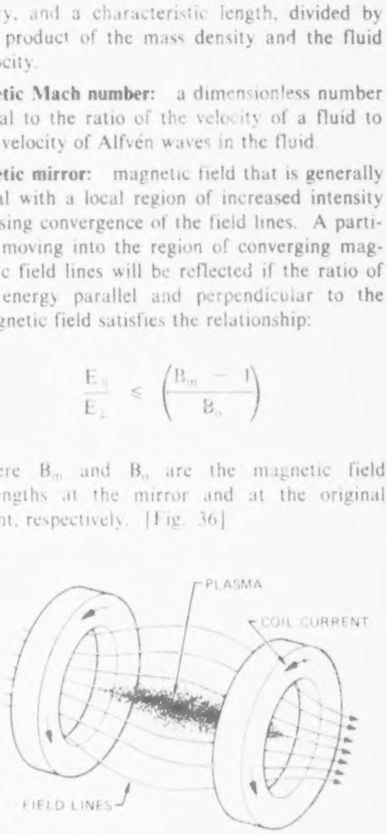


Fig. 36 Simple magnetic mirror.

magnetic moment: a vector associated with a magnet, current loop, or particle whose cross product with the magnetic induction of a magnetic field is equal to the torque exerted on the system by the field.

magnetic number: a dimensionless number equal to the square root of the magnetic force parameter.

magnetic pressure: the pressure that a magnetic field is capable of exerting upon a plasma, which is equivalent to the energy density of a magnetic field.

magnetic probe: a coil inserted in a magnetically confined plasma to measure changes in field strength.

magnetic pumping: term given to type of plasma heating in which plasma is successfully compressed and expanded by means of rapidly fluctuating external magnetic field.

magnetic stress tensor: a second-rank tensor, proportional to the dyad product of the magnetic induction with itself, whose divergence gives that part of the force of a magnetic field on a unit volume of conducting fluid which is due to curvature of flux lines.

magnetic viscosity: the effect, possessed by a magnetic field in the absence of sizable mechanical forces or electric fields, of damping motions of a conducting fluid perpendicular to the field similar to ordinary viscosity.

magnetic well: See **minimum-B configuration.**

magnetohydrodynamics: science dealing with the motion of electrically conducting fluids (liquids and gases) interacting with a magnetic field; also called **hydromagnetics.**

magnetohydrodynamic turbulence: motion of a plasma in which velocities and pressures fluctuate irregularly.

magnetohydrodynamic waves: material waves in an electrically conducting fluid in the presence of a magnetic field.

maximum permissible concentration (MPC): amount of radioactive material in air, water, or food that might be expected to result in a maximum permissible dose to persons consuming them at a standard rate of intake; an obsolescent term.

Maxwell–Boltzmann distribution: distribution of particle velocities (or energies) that occurs in any gas or plasma when it is in thermal equilibrium at a given temperature.

Maxwell equations: four differential equations relating electric and magnetic fields to electric charges and currents.

mean free path (for a given event): average distance a particle will travel before undergoing such an event.

medium-beta plasma: a plasma in which the beta value is typically 0.01 to 0.1.

MeV: one million (or 10^6) electron volts. (See **electron volt.**)

MFTF: Mirror Fusion Test Facility, large mirror machine experiment at Lawrence Livermore National Laboratory that uses a superconducting magnet of the Yin Yang design. Technical problems are addressed that must be solved before reactors can be attained. [Figs. 37, 38]

microwave interferometer: instrument that measures the electron density along a path through a plasma; density is derived from the phase

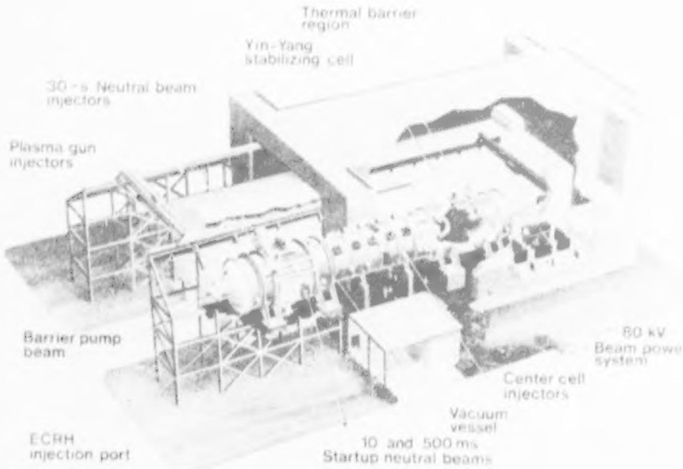


Fig. 37 MFTF-B.

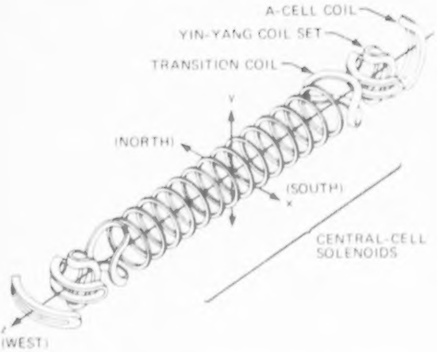


Fig. 38 The magnetic coil array used in the Mirror Fusion Test Facility.

shift of a microwave beam that traverses the path.

Migma devices: nonplasma, nonthermal, nonpulsed devices in which fusion occurs among the ions of a self-colliding beam.

minimum-B configuration: name given to a magnetic configuration that increases everywhere in strength with increasing distance from the plasma it is confining. In such a configuration the plasma finds itself in a region of minimum magnetic potential.

mirror ratio: in a magnetic mirror configuration, the ratio of the strength of the magnetic field at the strongest point on its axis to that at some other axial point (usually taken to be the point of weakest field strength between two magnetic mirrors).

mobility: equilibrium drift velocity attained by a charged particle when subjected to acceleration by a unit electric field and to the opposing frictional force of collisions with other particles.

molecular ion injection concept: concept under investigation in the field of controlled fusion, in which energetic molecular ions are injected into a suitable magnetic container and are dissociated therein by any of several processes (e.g., collision with neutral atoms, Lorentz dissociation, etc.). The density of trapped energetic atomic ions is then built up to values of thermonuclear interest, with the simultaneous conversion of their directed velocities into the random motion of a hot plasma.

nano: prefix that divides a basic unit by one billion (10^9).

NASA Lewis bumpy torus: toroidal array of 12 superconducting coils in a large vacuum tank. Objective is to optimize steady-state plasma heating and containment by applying strong electric fields to plasma in a closed magnetic field geometry.

neoclassical: term used to characterize results of elementary calculation of collisional diffusion in finite toroidal geometries.

neutral injection concept: concept similar to that described under molecular ion injection concept, but with the molecular ions replaced by fast neutral atoms which are subsequently ionized inside the magnetic container. [Fig. 39]

neutralized plasma: plasma with no net charge.

neutron: [symbol: n] uncharged elementary particle with mass slightly greater than that of the proton, and found in the nucleus of every atom heavier than hydrogen. A free neutron is unstable and decays with a half-life of about 13 minutes into an electron, proton, and neutrino. Neutrons sustain the fission chain reaction in a nuclear reactor. (See **fast neutron** and **thermal neutron**.)

neutron wall loading: energy flux carried by fusion neutrons into the first physical boundary that surrounds the plasma.

nonlinearity: the deviation of any functional relationship from direct proportionality.

NOVA: a proposed Nd-glass laser facility at Lawrence Livermore National Laboratory that will focus 200 to 300 TW on fusion targets and thus drive high-gain microexplosions. [Fig. 40]

NUMAK reactors: University of Wisconsin tokamak upgrade of UWMAK I, II, and III.

ohmic heating: heating resulting from the resistance a medium offers to the flow of electric current; often called "joule heating." In plasma subjected to ohmic heating, ions are heated almost entirely by transfer of energy from the hotter electrons.

ohmic heating coil: windings in a tokamak which act as a transformer primary to initiate and increase the discharge current and permit heating by ohmic or joule effects within the plasma. [Fig. 41]

OMEGA facility: a large Nd-laser facility at the University of Rochester to be used in basic laser fusion experiments.

open system: See **magnetic mirror**.

optical interferometer: an instrument that employs the interference of light waves to measure the accuracy of optical surfaces and can measure a length in terms of the length of a wave of light by utilizing interference phenomena based on the wave characteristics of light; used extensively for testing optical elements during manufacture.

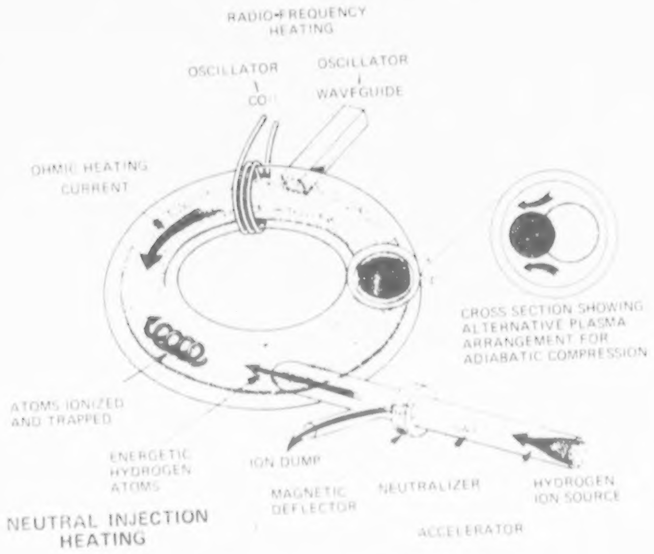


Fig. 39 Main heating systems for tokamaks.

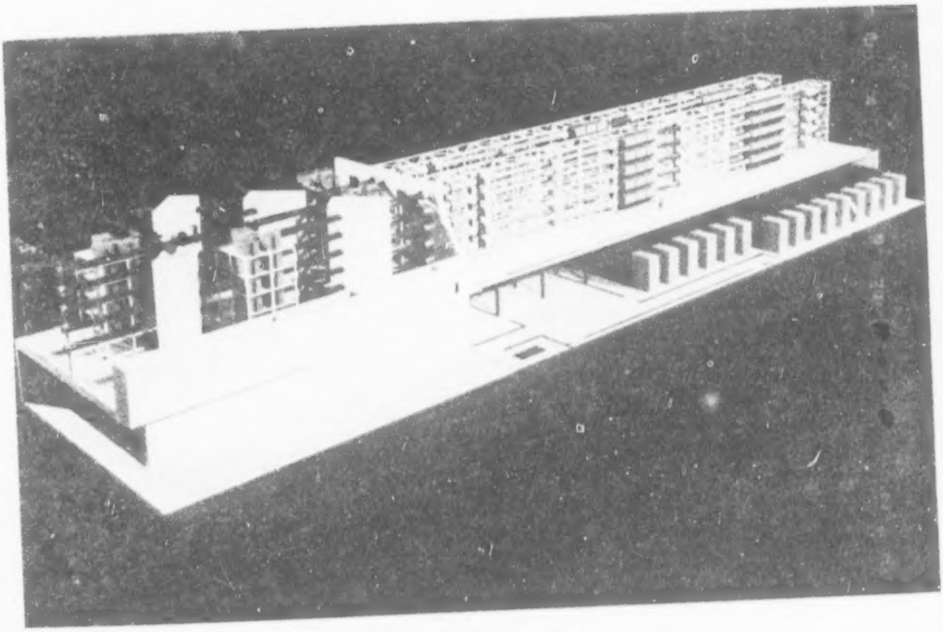


Fig. 40 NOVA, Phase 1.

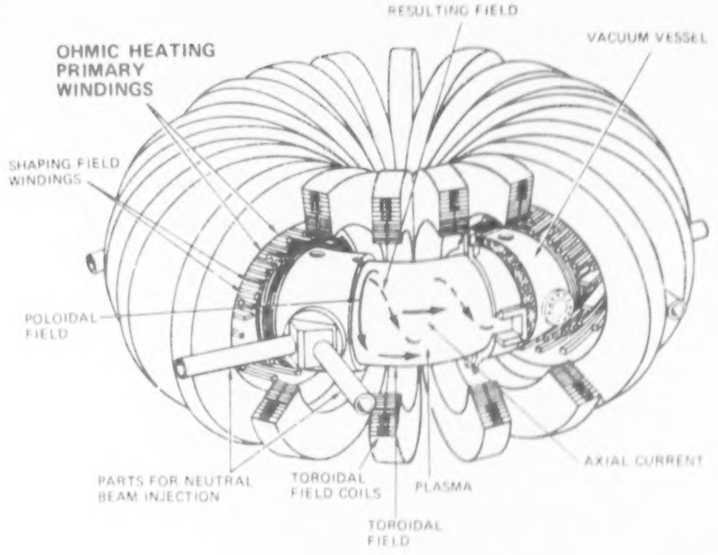


Fig. 41 Basic components of the tokamak.

optical pumping: process whereby absorbed radiation is stored in the laser medium. Laser action extracts the stored energy increasing the energy of the transmitted laser pulse.

oscillator: device to generate coherent optical energy. Generally consisting of a laser medium placed within an optical cavity (mirror pair). Optical energy will circulate within the cavity as long as the gain of the laser medium exceeds the losses at the mirrors.

overturning moment: toroidal field coil moment (in a tokamak) about the device radial direction from out-of-plane forces arising from vertical fields and from the plasma field.

parametric instability: that which occurs in a system whose equilibrium is weakly modulated in time or space. The modulation produces a coupling of the linear eigenmodes of the unmodulated system and can lead to destabilization.

PBFA: **P**article **B**eam **F**usion **A**ccelerator, a 30-TW, 1-MJ, 36-line accelerator to be used in the inertial confinement fusion program. [Fig. 42]

PDX: **P**oloidal **D**ivertor **EX**periment, large high-current divertor tokamak at Princeton whose primary objective is to determine the effectiveness of magnetic limiters and poloidal divertors in controlling impurities in hot reactor-like plasmas. [Fig. 43]

Pfirsch-Schlueter regime: the transport regime in a tokamak plasma characterized by the mean free path being shorter than the connection length. In this regime the diffusion coefficient is q^2 times the classical value, where the safety factor q is greater than or equal to 1.

pinch effect: constriction of a plasma column carrying a large current, caused by the interaction of that current with its own encircling magnetic field. [Fig. 44]

plant factor: ratio of the average power load of an electric power plant to its rated capacity; sometimes called capacity factor.

plasma: ionized gaseous system, composed of an electrically equivalent number of positive ions and free electrons, irrespective of the presence of neutral particles; in view of its abundance in the universe, sometimes called "the fourth state of matter."

plasma, cold: See **cold plasma.**

plasma, collisionless: See **collisionless plasma.**

plasma containment: operation intended to prevent, in an effective and sufficiently prolonged manner, the particles of a plasma from striking the walls of the container in which this plasma is produced.

plasma frequency: natural frequency of oscillation of a plasma, caused by the collective motion of the electrons acting under the restoring force of their space-charge attraction to the

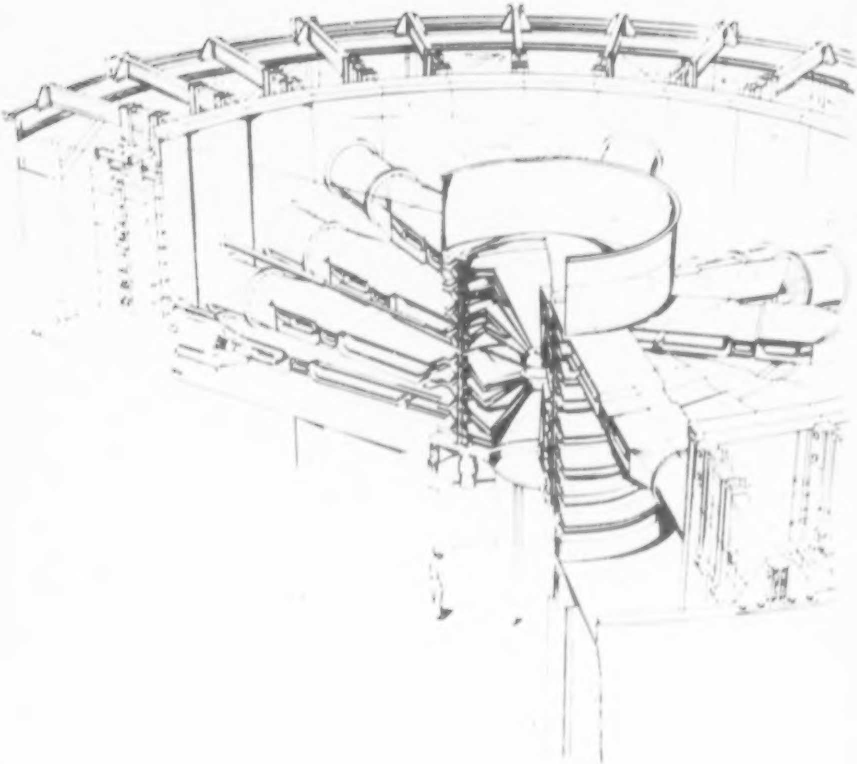


Fig. 42 Particle Beam Fusion Accelerator.

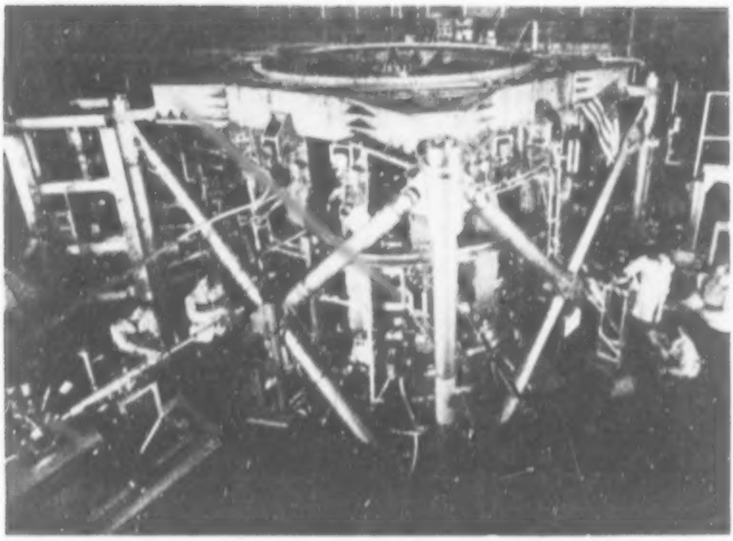


Fig. 43 Poloidal Divertor Experiment (PDX).

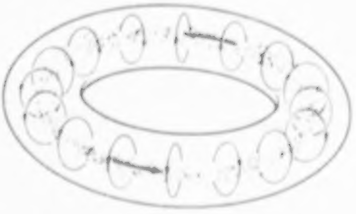


Fig. 44 Representation of the pinch effect in a torus. The darker ring is the plasma in which an electric current is induced; the circles surrounding the plasma indicate the poloidal magnetic field produced by the current.

relatively stationary ions. The frequency is proportional to the square root of the electron density.

plasma gun: apparatus intended to produce high-velocity puffs of plasma.

plasma instability: state of a plasma in which any small perturbation amplifies itself to a considerable alteration of the equilibrium of the system.

plasma radiation: electromagnetic radiation emitted from a plasma, primarily by free electrons undergoing transitions to other free states or to bound states of atoms and ions, but also by bound electrons as they undergo transitions to other bound states.

plasma wave: a disturbance of plasma involving oscillation of its constituent particles and of an electromagnetic field, which propagates from one point in the plasma to another without net motion of the plasma.

plasmoid: an isolated collection of electrons, ions, and neutral particles which holds together for a duration many times as long as the collision times between particles.

plateau region: the collision frequency regime characterized by an effective coulomb scattering rate equal to or greater than the poloidal transit frequency, but a mean free path length less than the connection length. In this regime, the transport coefficients are independent of collision frequency.

PLT: Princeton Large Torus, large toroidal apparatus of the tokamak type, to operate without a copper shell. The purpose is to study heating and confinement of high-temperature plasmas with a plasma diameter roughly the geometric mean of present devices and proposed fusion reactors. [Figs. 45, 46]

Pockels cell: certain single crystals exhibit the Pockels effect whereby a voltage applied across the crystal causes an increase in retardation between the two orthogonal vectors induced by the crystal on the plane polarized light propagating through the crystal. The magnitude of retardation induced by the electric field is directly proportional to it. A crossed

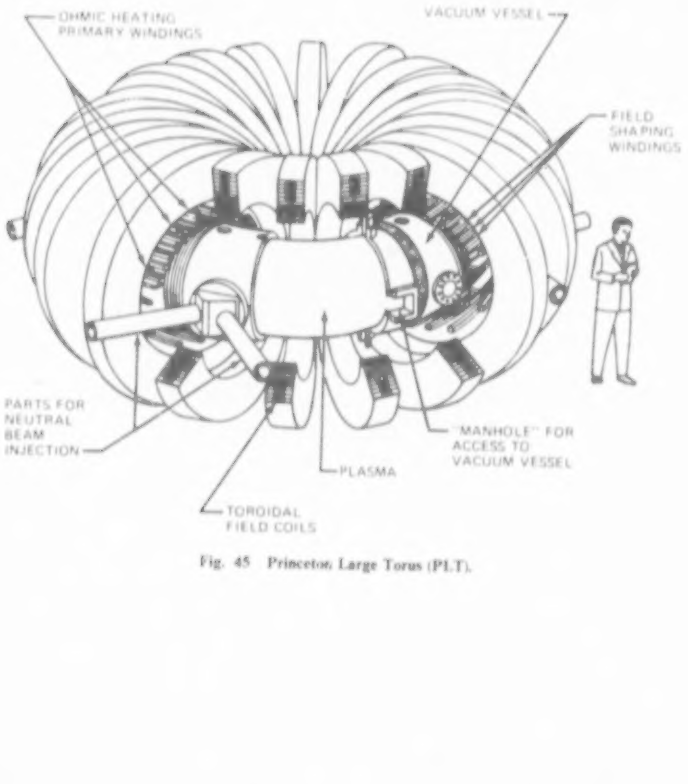

OHMIC HEATING PRIMARY WINDINGS
VACUUM VESSEL
FIELD SHAPING WINDINGS
PARTS FOR NEUTRAL BEAM INJECTION
"MANHOLE" FOR ACCESS TO VACUUM VESSEL
PLASMA
TOROIDAL FIELD COILS

Fig. 45 Princeton Large Torus (PLT).

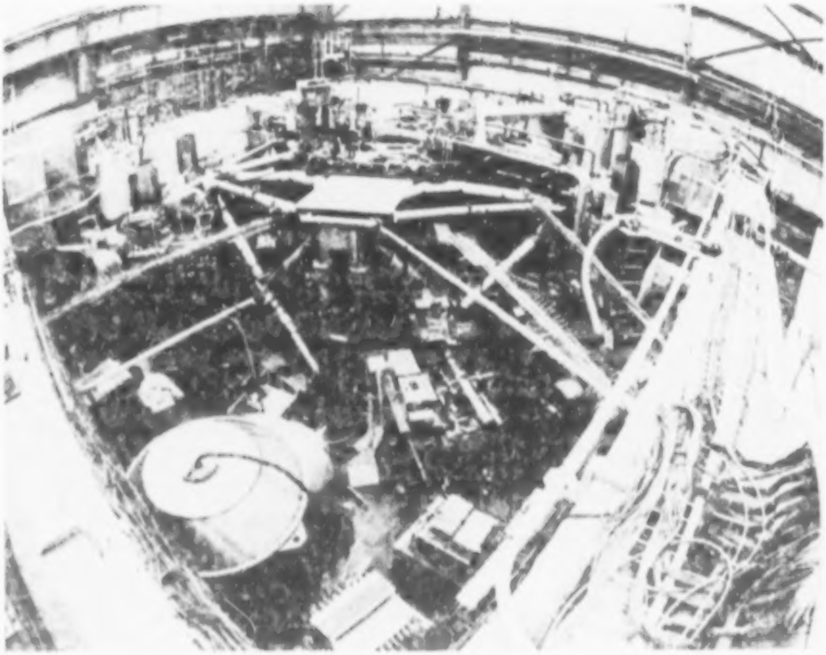


Fig. 46 Princeton Large Torus (PLT).

polarizer analyzes the emergent beam. Response time can be in nanoseconds.

poloidal divertor: a divertor which takes out poloidal magnetic field lines, forming a separatrix in the poloidal field. [Fig. 47]

poloidal field: magnetic field that encircles the plasma axis in toroidal devices.

poloidal field windings: sets of windings in toroidal devices which are aligned along the plasma axis and produce poloidal fields. These include ohmic heating, shaping, vertical, equilibrium, and divertor windings. [Fig. 48]

positive column: the luminous glow, often striated, that occurs between the Faraday dark space and the anode in a glow discharge tube.

power density: rate of heat generated per unit volume of a reactor core.

pressure tensor: a tensor which plays a role in magnetohydrodynamics analogous to that of pressure in ordinary fluid mechanics.

Project Sherwood: name often used to designate the U. S. program in controlled fusion during the 1950s and 1960s.

Proto II: an accelerator capable of providing a 10^{13}-W, 24-ns electron beam pulse which can be directed as two beams onto a several-millimeter-size fuel pellet. [Fig. 49]

proton: [symbol: p] elementary particle with a single positive electrical charge and a mass approximately 1837 times that of the electron, the nucleus of an ordinary or light hydrogen atom. Protons are constituents of all nuclei. The atomic number (Z) of an atom is equal to the number of protons in its nucleus.

PULSAR concept: a system which produces pulsed power by magnetic flux compression with metallic or plasma armatures.

pulse height analyzer: an instrument capable of indicating the number of pulse occurrences falling within each of one or more specified amplitude ranges.

pumpout: name given to the anomalously high loss of particles to the walls in stellarator discharges a loss rate substantially in excess of that expected from normal classical diffusion processes.

quasi-linear theory: a weakly nonlinear theory of plasma oscillations which uses perturbation theory and the random pulse approximation to find the time development of the plasma state.

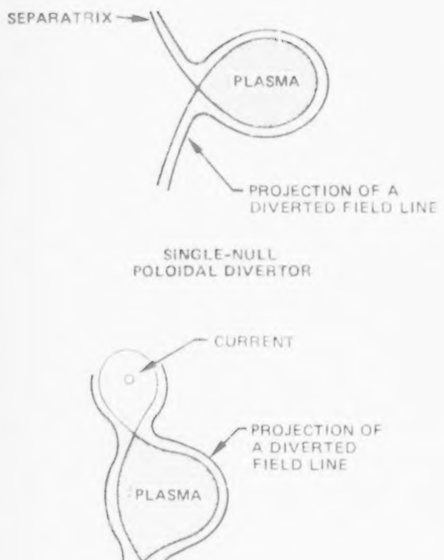

SEPARATRIX
PLASMA
PROJECTION OF A DIVERTED FIELD LINE
SINGLE-NULL POLOIDAL DIVERTOR
CURRENT
PROJECTION OF A DIVERTED FIELD LINE
PLASMA
DOUBLE-NULL POLOIDAL DIVERTOR

Fig. 47 Types of poloidal divertors.

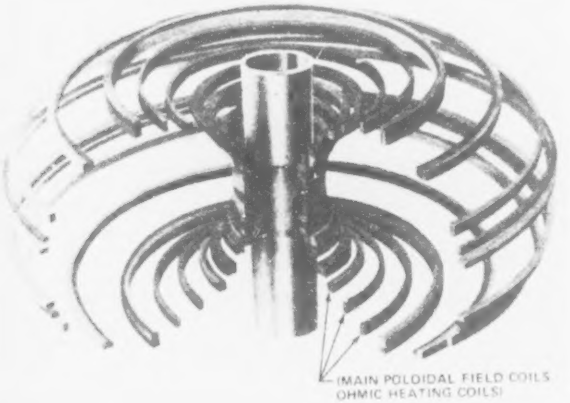


Fig. 48 Cutaway model of the poloidal magnetic field coils in a tokamak (TFTR). A time-varying current in the coils near the center induces the plasma current that generates the main poloidal field. This current also serves to heat the plasma and so the inner coils are often called the "ohmic heating coils." The other coils produce magnetic fields that modify the main poloidal field and control the location of the plasma within the torus.

Q-switch: optical switch used to rapidly change the Q of an optical resonator; utilized in the optical resonator of a laser to prevent lasing action until a high level of optical gain and energy storage are achieved in the laser rod. When the switch rapidly increases the Q of the cavity, a giant pulse is generated.

rad: **r**adiation **a**bsorbed **d**ose, basic unit of absorbed dose of ionizing radiation. Dose of one rad means absorption of 100 ergs of radiation energy per gram of absorbing material.

radiation: emission and propagation of energy through matter or space by means of electromagnetic disturbances which display both wave-like and particle-like behavior; in this context the "particles" are known as photons; also, the energy so propagated. The term has been extended to include streams of fast-moving particles (alpha and beta particles, free neutrons, cosmic radiation, etc.). Nuclear radiation is that emitted from atomic nuclei in various nuclear reactions, including alpha, beta, and gamma radiation and neutrons.

radiation damage, bulk: general term describing changes in chemical and/or metallurgical properties of structure components of fusion reactors caused by atomic displacement and nuclear transmutation [e.g., via (n, α) or (n, p) reactions] events occurring as the result of higher-energy neutron environment.

radiation damage, surface: general term describing damage to the surface of the containment structure which directly interfaces with the thermonuclear plasma; includes such phenomena as radiation blistering, charged-particle (or neutron) sputtering, and spallation or exfoliation of layers of the surface.

radioactive decay: spontaneous transformation of one nuclide into a different nuclide or into a different energy state of the same nuclide.

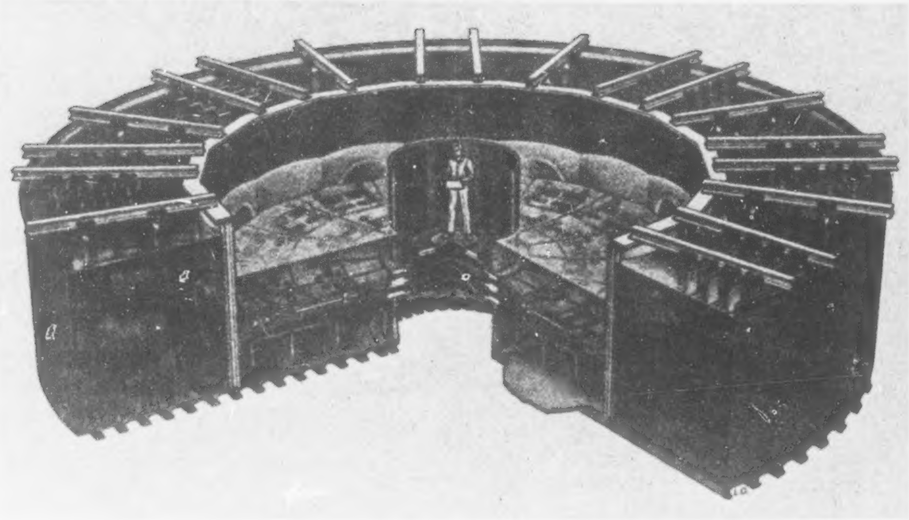


Fig. 49 Proto II.

Process results in a decrease, with time, of number or original radioactive atoms in a sample. It involves the emission from the nucleus of alpha particles, beta particles (or electrons) or gamma rays; or the nuclear capture or ejection of orbital electrons; or fission; also called radioactive disintegration.

radioactive waste: equipment and materials (from nuclear operations) which are radioactive and for which there is no further use. Wastes are generally classified as high-level (having radioactivity concentrations of hundreds to thousands of curies per gallon or cubic foot), low-level (in the range of 1 microcurie per gallon or cubic foot), or intermediate (between these extremes).

railgun accelerator: projectile acceleration occurs when a conducting particle completes the current connection between two conducting rails connected to a source of high current. [Fig. 50]

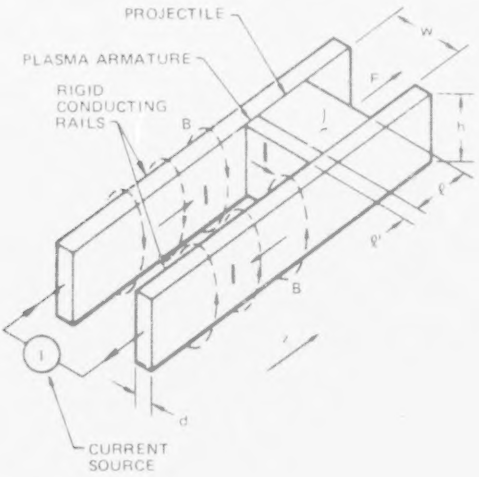


Fig. 50 Railgun accelerator.

Raman effect: a phenomenon observed in the scattering of light as it passes through a transparent medium; the light undergoes a change in frequency and a random alteration in phase due to a change in rotational or vibrational energy of the scattering molecules.

recombination coefficient: the rate of recombination of positive ions with electrons or negative ions in a gas per unit volume divided by the product of the number of positive ions per unit volume and the number of electrons or negative ions per unit volume.

reflectivity: property of a reflecting surface which is that fraction of the incident radiant energy reflected by a surface. The remaining power is either absorbed or transmitted.

refraction: bending of oblique incident rays as they pass from a medium having one refractive index into a medium having a different refractive index.

rem: roentgen equivalent man, unit of dose of any ionizing radiation that produces the same biological effect as a unit of absorbed dose of ordinary X rays. The RBE dose (in rems) = RBE × absorbed dose (in rads). (Compare **curie; roentgen**.)

resistive instability: instability resulting from macroscopic equations of a plasma of a finite electric conductivity.

roentgen: [abbreviation: r] unit of exposure to ionizing radiation. It is that amount of gamma or X rays required to produce ions carrying 1 electrostatic unit of electrical charge (either positive or negative) in 1 cubic centimeter of dry air under standard conditions. Named after Wilhem Roentgen, German scientist who discovered X rays in 1895. (Compare **curie; rad; rem**.)

Rogowski loop: coiled wire loop which encircles a current-carrying plasma. Changes in the plasma current induce a voltage in the loop. Integrating the voltage over time gives the plasma current.

Rotating Target Neutron Source (RTNS): 14-MeV neutron source at Lawrence Livermore National Laboratory with the purpose of obtaining data on fusion materials at high doses.

rotational transform: a magnetic field configuration is said to possess rotational transform if the lines of force, after one circuit around the configuration (e.g., a torus), do not close exactly on themselves but are rotated through some angle about the so-called magnetic axis. [Fig. 51]

runaway electrons: those electrons in a plasma that gain energy from an applied electric field at a faster rate than they lose it through collisions. Since the collision cross section decreases as the velocity increases, these electrons tend to "run away" in energy from the remainder of the plasma.

safety factor: the inverse of the rotational transform of a toroidal magnetic confinement system. The value of the safety factor $q = (rB_T/RB_p)$ must exceed unity to avoid long-wavelength kink instabilities.

scaling laws: laws stating that if two quantities are proportional and are known to be valid at certain orders of magnitude, then they can be used to calculate the value of one of the quantities at another order of magnitude.

scattering: deflection of one particle as a result of collision with another. Elastic scattering is a scattering process in which the total kinetic energy is unchanged.

Schlieren method: an optical technique that detects density gradients occurring in a fluid flow. In its simplest form, light from a slit is collimated by a lens and focused onto a knife edge by a second lens; the flow pattern is placed between the two lenses, and the resulting diffraction pattern is observed on a screen or photographic film placed behind the knife edge.

scientific feasibility: successful completion of experiments which reach "break even" plasma conditions (minimum values of density, temperature, and plasma confinement time) in

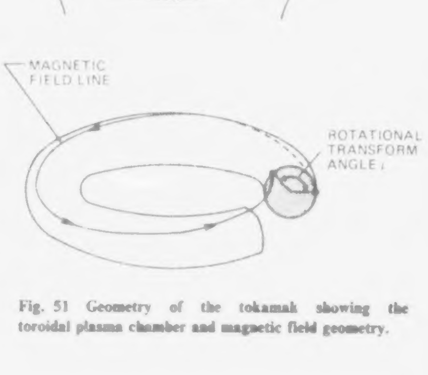


Fig. 51 Geometry of the tokamak showing the toroidal plasma chamber and magnetic field geometry.

laboratory configurations which lend themselves to development into net power producing systems. Fusion fuels need not necessarily be used in these experiments.

screw pinch: a theta pinch in which axial currents produce a poloidal magnetic field (in addition to the usual longitudinal field), thus making a corkscrew field configuration.

separatrix points: the interaction of two separatrices. In the case of magnetic field configurations, points where $B_p = 0$ and a change in magnetic surface topology occurs. [Fig. 52]

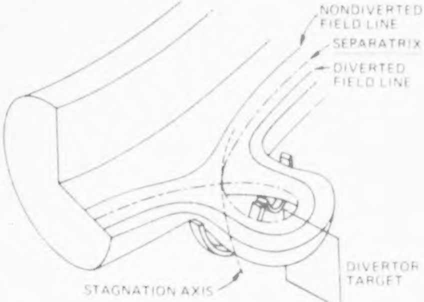


Fig. 52 Schematic of tokamak equipped with a bundle divertor. Principal features of the magnetic configuration are shown.

shear fields: in use in plasma physics, magnetic fields having a rotational transform that changes with radius (e.g., in the stellarator tube, magnetic fields that increase in pitch with distance from the axis). [Fig. 53]

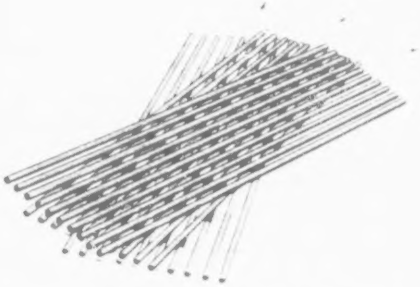


Fig. 53 Shear fields showing that the lines of force in one plane are twisted with respect to those in adjacent planes.

sheath: region of transition between a neutral plasma and a solid surface in contact with it. While the plasma itself is nearly an equipotential region, there exists a strong potential gradient within the sheath itself, and electrical neutrality in that region is not preserved.

SHIVA: 20-beam Nd-glass laser facility at Lawrence Livermore National Laboratory capable of depositing 27 TW on a fuel pellet. [Figs. 54, 55]

shock heating: heating produced by the impact of a shock wave.

shock tube: a gas-filled tube used in plasma physics to quickly ionize a gas. A capacitor bank charged to a high voltage is discharged into the gas at one tube end to ionize and heat the gas, producing a shock wave that may be studied as it travels down the tube.

shock wave: wave produced (e.g., in a gas) as a result of a sudden violent disturbance. To produce a shock wave in a given region, the disturbance must take place in a shorter time than the time required for sound waves to traverse that region.

solid-state laser: a laser using a transparent substance (crystalline or glass) as the active medium, doped to provide the energy states necessary for lasing. The pumping mechanism is the radiation from a powerful light source, such as a flashlamp. The ruby, Nd-YAG, and Nd:glass lasers are solid-state lasers.

solitons: stable, shape-preserving and localized solutions of nonlinear classical field equations of recent interest as possible models of extended elementary particles.

spaceframe: three-dimensional optical bench that holds laser components stable from vibrational and thermal excursions.

spallation: See **radiation damage, surface.**

spatial filter: device consisting of a lens pair and a pinhole aperture stop. Intensity fluctuations over the spatial extent of a laser beam are removed by passing the focused beam through the aperture stop. The pinhole must be placed in a vacuum to prevent air breakdown by the focused beam. These filters are used to counter the effects caused by self-focusing.

spherator: single-ring multipole device with an additional current-carrying rod perpendicular to the ring axis.

Spheromak (S-1): a device to generate a plasma by using quasi-static inductive forming techniques so as to minimize peak power requirements and plasma electrode contact. The reactor advantages of the Spheromak are its large engineering beta value and the fact that the coils and blanket do not topologically link the plasma.

spontaneous emission: radiation randomly emitted by excited neodymium ions in the Nd:glass laser medium.

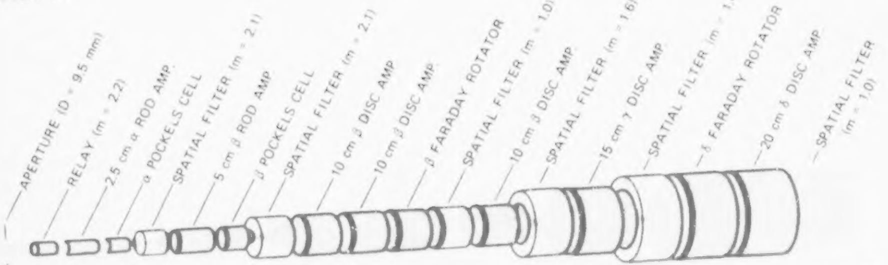


Fig. 54 A schematic illustration of a SHIVA laser chain. Labels on each amplifier give the nominal clear aperture. The number in parentheses after each spatial filter gives the magnification of the beam diameter by that spatial filter.

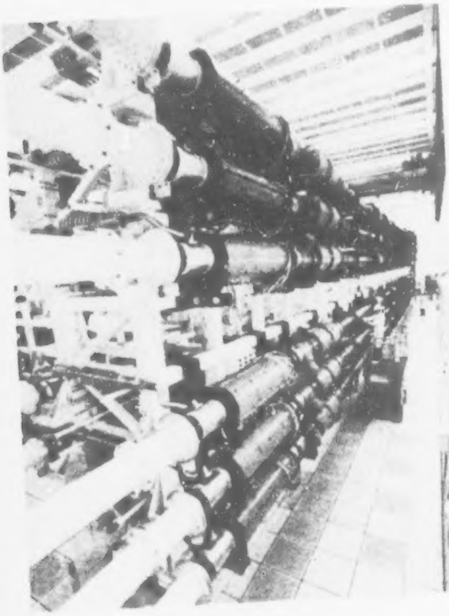


Fig. 55 SHIVA.

sputtering: See **radiation damage, surface.**

Starfire tokamak: a conceptual design study of a modular tokamak reactor that operates in a steady-state condition while using conventional power-generating systems. [Fig. 56]

Stark effect: the effect on spectrum lines of an electric field which is either externally applied or is an internal field caused by the presence of neighboring ions or atoms in a gas, liquid, or solid.

stellarator: apparatus designed for the containment of a plasma inside a tube closed upon itself by using the combination of an axial magnetic field and of an additional field created by the helical windings. This magnetic configuration presents a rotational transformation in itself and permits containment in the absence of an axial current in the plasma. [Fig. 57]

stimulated emission: radiation coherently emitted by excited Nd ions when driven by a passing light wave at precisely the laser wavelength. Since the phase and amplitude of the stimulated wave depend on the stimulating wave, this radiation is coherent with the stimulating wave. The rate of stimulated emission is proportional to the intensity of the stimulating wave.

Sturm–Liouville problem: the general problem of solving a linear differential equation of order 2n together with 2n-boundary conditions; also known as the eigenvalue problem.

superconductor: type of conductor that permits an electrical current to flow with zero resistance.

synchrotron radiation: See **cyclotron radiation.**

T-20: a large Russian tokamak that will operate under reactor conditions.

target plasma: plasma used to trap a neutral atom beam. A background plasma of sufficiently high density and temperature can ionize neutral atoms more effectively than the Lorentz process.

tearing instability: resistive instability which is spatially localized near a rational magnetic surface and which grows at a rate slower than the MHD Alfvén rate but faster than the skin diffusion rate. The instability "tears" poloidal field lines and reconnects them into a new state of lower magnetic energy.

temperature, kinetic: See **kinetic temperature.**

TEXT device: Texas **EX**perimental Tokamak intended for diagnostic development and basic physics experiments including rf heating.

TFR tokamak: an iron-core French tokamak that produces a 1-keV ion temperature plasma with a density in the range of 10^{13}

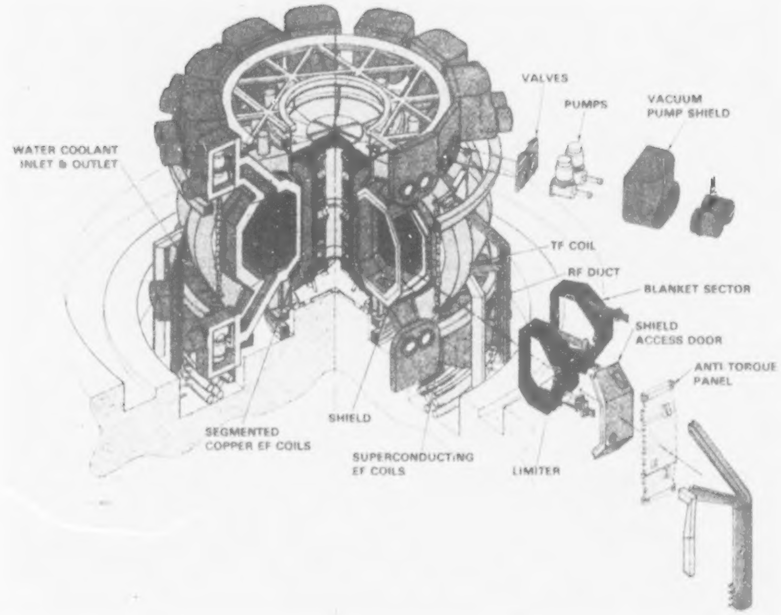


Fig. 56 Starfire tokamak.

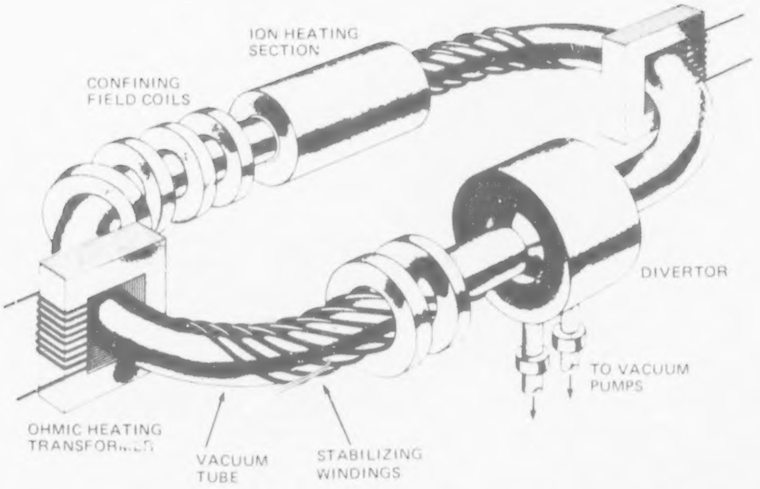


Fig. 57 The Model C Stellarator, built to test components for a full-scale device and to study the properties of high-temperature plasmas. (The confining field coils and stabilizing windings actually go around the entire tube. Some were omitted in the drawing to show detail.)

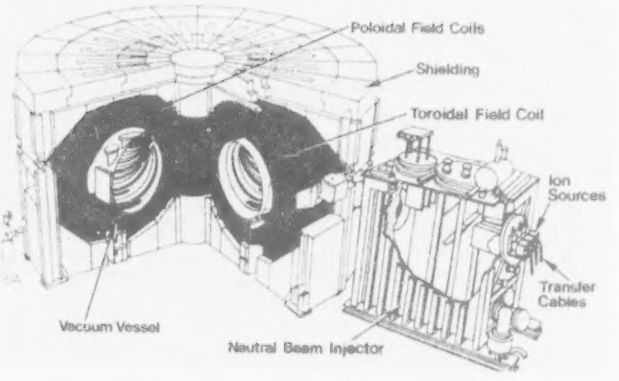


Fig. 58 Tokamak Fusion Test Reactor (TFTR).

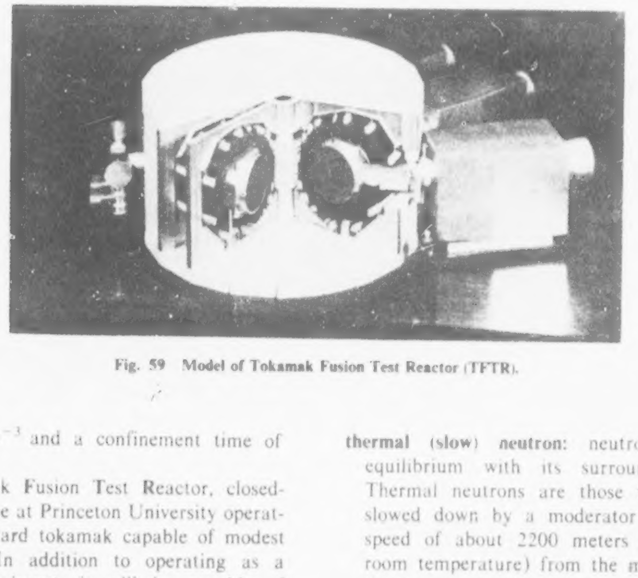


Fig. 59 Model of Tokamak Fusion Test Reactor (TFTR).

particles · cm^{-3} and a confinement time of 10 ms.

TFTR: Tokamak Fusion Test Reactor, closed-geometry device at Princeton University operating as a standard tokamak capable of modest compression. In addition to operating as a hydrogen experiment, it will be capable of injecting high-energy neutral deuterium into a tritium plasma in the two-energy component mode, producing a D-T plasma under reactor conditions. [Figs. 58, 59]

thermal conversion cycle: generation of electrical power with a fusion reactor by means of a steam or metal vapor turbine. This process is distinct from "direct conversion" cycles.

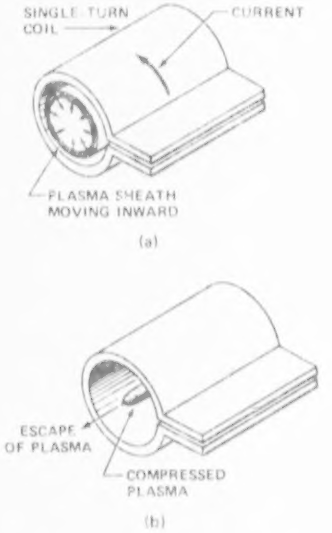
thermal efficiency: ratio of the electric power produced by a power plant to the amount of heat produced by the fuel; a measure of the efficiency with which the plant converts thermal to electrical energy.

thermal (slow) neutron: neutron in thermal equilibrium with its surrounding medium. Thermal neutrons are those that have been slowed down by a moderator to an average speed of about 2200 meters per second (at room temperature) from the much higher initial speeds they had when expelled by fission. This velocity is similar to that of gas molecules at ordinary temperatures. (Compare **fast neutron**.)

thermodynamic equilibrium: very general result from statistical mechanics which states that, if a system is in equilibrium, all processes that can exchange energy must be exactly balanced by the reverse process so that there is no net exchange of energy. For instance, ionization must be balanced by recombination, Bremsstrahlung by absorption, etc. If a plasma complies with this statement, the distribution function of particle energies and excited energy levels of the atoms can be obtained from the Maxwell Boltzmann distribution which is a function only of the temperature. Saha's equation is a special application of this result and gives the distribution function or density of ions and electrons.

thermonuclear conditions: achievement of an adequately confined plasma having temperature and density sufficiently high to yield significant release of energy from fusion reactions.

theta pinch: fast-pulsed device in which a fast-rising, strong (100-kG) magnetic field compresses and heats a plasma in a few microseconds; magnetic field is parallel to axis of a cylindrical column. [Fig. 60]



(a)

(b)

Fig. 60 Development of a theta pinch: (a) shock-heating phase and (b) quiescent compression phase.

Thomson scattering: scattering of photons by electrons. A technique based on Thomson scattering is used to measure electron temperature in a plasma; the spread in the energy distribution of laser light that has been scattered in a plasma is proportional to the electron temperature.

thorium: [symbol: Th] naturally radioactive element with atomic number 90 and, as found in nature, an atomic weight of approximately 232. The fertile thorium-232 isotope is abundant and can be transmuted to fissionable uranium-233 by neutron irradiation.

TMX device: Tandem Mirror EXperiment at LLNL, a mirror device that uses solenoidal coils coupled to mirror end cells. [Figs. 61, 62]

tokamak: name given to a specific concept in the field of controlled fusion, involving confinement and heating of a plasma in a toroidal configuration. A large current induced in the plasma provides the rotational transform necessary for confinement while simultaneously heating the plasma. [Fig. 63]

TORMAC: **TOR**oidal **MA**gnetic **C**usps, a hybrid confinement system operating at high beta. A region of closed toroidal magnetic flux with high-beta plasma is separated by a narrow sheath from the surrounding field which contains externally produced poloidal components arranged in a toroidal line-cusp configuration. Plasma migrating to the outer sheath is temporally mirror-confined before being removed in a divertor system. [Fig. 64]

toroidal field coils: coils in a toroidal system which provide the major confining field. Each turn completely surrounds the minor axis of the plasma.

toroidal system: name given to the general class of "doughnut-shaped" magnetic fields in which lines of force close on themselves. Stellarators, tokamaks, and multipole devices are examples of this class of devices.

torsatron: a modification of the stellarator concept. It has a toroidal non-axisymmetric configuration, and rotational transform is provided by external windings. Unlike a stellarator, however, both toroidal and poloidal fields are generated by helical fields alone, with half the number of helical conductors required for a stellarator.

transmittance: ratio of the radiant power transmitted by an object to the incident radiant power.

transmutation: transformation of one element into another by a nuclear reaction or series of reactions (e.g., the transmutation of uranium-238 into plutonium-239 by absorption of a neutron).

trapped-particle instability: slowly growing class of instabilities driven by particles which cannot circulate freely in a toroidal system.

tritium: an isotope of the hydrogen atom with one proton and two neutrons in its nucleus and a single orbital electron.

triton: the nucleus of a tritium (^3H) atom. (See **hydrogen; tritium**.)

turbulence: violent macroscopic fluctuations which can develop under certain conditions in fluids and plasmas and which usually result in

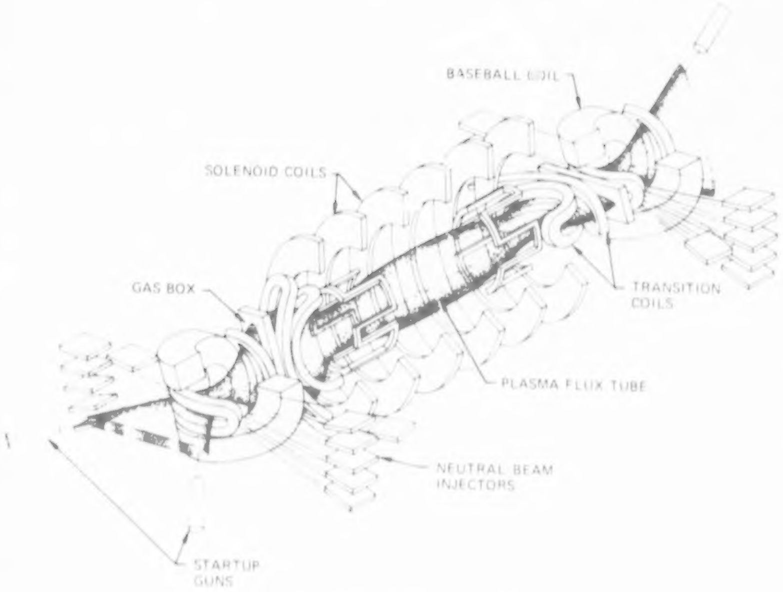


Fig. 61 Schematic drawing of TMX.

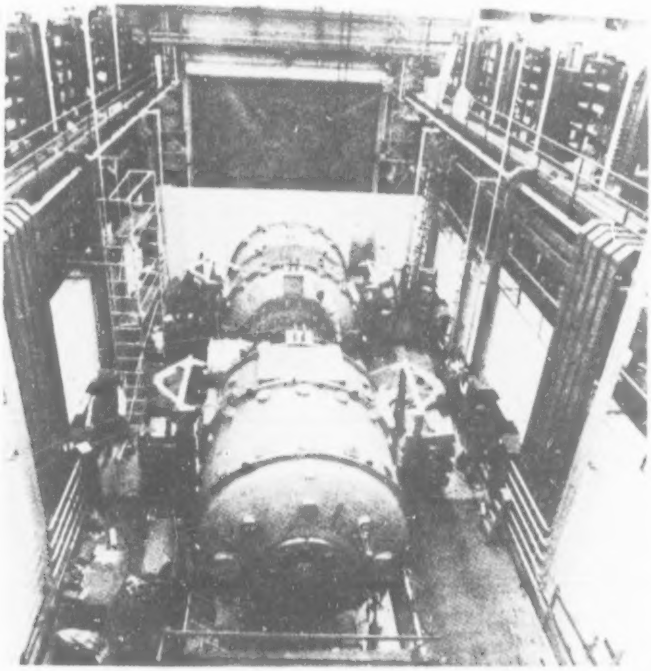


Fig. 62 TMX device.

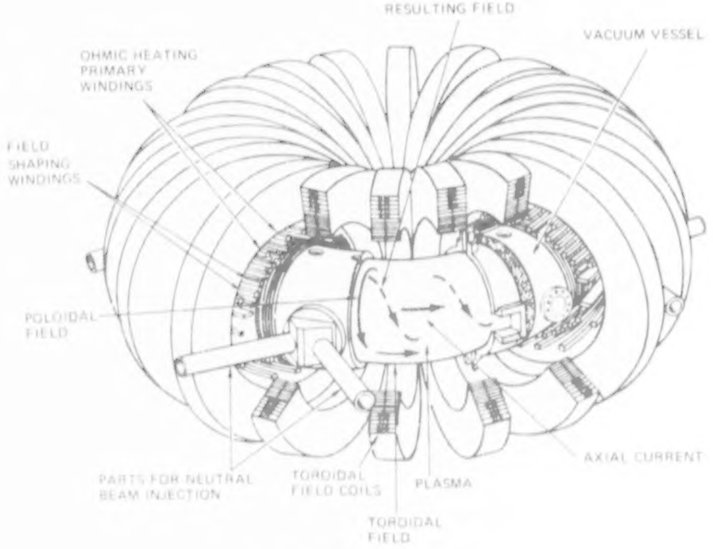


Fig. 63 Basic components of the tokamak.

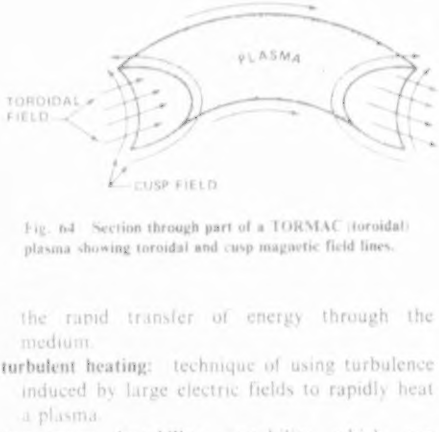


Fig. 64 Section through part of a TORMAC (toroidal) plasma showing toroidal and cusp magnetic field lines.

the rapid transfer of energy through the medium.

turbulent heating: technique of using turbulence induced by large electric fields to rapidly heat a plasma.

two-stream instability: instability which can develop when a stream of particles of one type has a velocity distribution with its peak well separated from that of another type of particle through which it is flowing. A stream of energetic electrons passing through a cold plasma can, for example, excite ion waves which will grow rapidly in magnitude at the expense of the kinetic energy of the electrons.

unipolar arc: arc between a metal surface and a plasma in contact with it. Such an arc requires only one electrode and is maintained by the thermal energy of the electrons.

universal instability: low-frequency instability resulting from presence of density gradients perpendicular to the magnetic field lines. An instability of this type is generally localized and usually has a small rate of growth.

velocity space instability: a class of instabilities driven by particle distributions which are not in thermal equilibrium.

vertical field windings: See **field shaping coils.**

voltage loop: a wire which encircles the main axis of a tokamak in the vicinity of the vacuum vessel. The voltage induced in this loop is a measure of the ohmic heating voltage applied around the toroid.

wall loading: fusion reactor thermal output power divided by the area of the wall facing the plasma.

waste, radioactive: See **radioactive waste**.

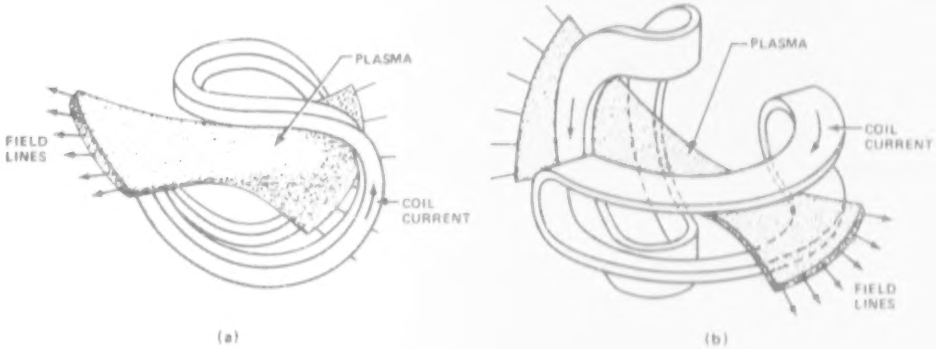
wavelength: the length of a wave measured from any point on the next wave, usually measured from crest to crest. Wavelength defines the nature of the various forms of radiant energy that compose the electromagnetic spectrum, and it determines the color of light. Common units for measurement are the micron, the nanometer or millimicron, and the angstrom.

Wendelstein VII A stellarator: West German toroidal l = 2, m = 5 stellarator with air core transformer for ohmic heating (at Max-Planck Institut fuer Plasmaphysik, Garching/Muenchen).

whistler: a wave in a plasma which propagates parallel to the magnetic field produced by currents outside the plasma at a frequency less than that of the electron cyclotron resonance and which is circularly polarized, rotating in the same sense as electrons in the plasma; also known as **electron cyclotron wave**.

X ray: a penetrating form of electromagnetic radiation emitted either when the inner orbital electrons of an excited atom return to their normal state (characteristic X rays) or when a metal target is bombarded with high-speed electrons (bremsstrahlung). X rays are always nonnuclear in origin. (Compare **bremsstrahlung; gamma rays**.)

Yin–Yang coil: nested coil pair used in mirror devices to produce a magnetic well or minimum-B configuration. [Figs. 65, 66]



(a)

(b)

Fig. 65 Magnetic well configurations, in which the field strength increases from the center outward in all directions, generated by current passing through (a) a coil shaped like the seam of a baseball (or tennis ball) and (b) Yin–Yang coils. In both cases two fan-shaped mirror fields are formed at right angles to each other.

Fig. 66 Yin–Yang magnet coils for MFTF-B.

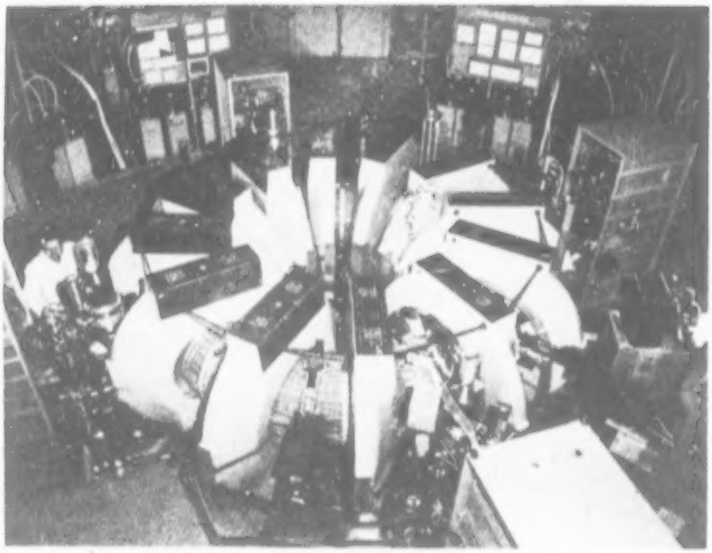


Fig. 67 ZT-40 reversed field pinch.

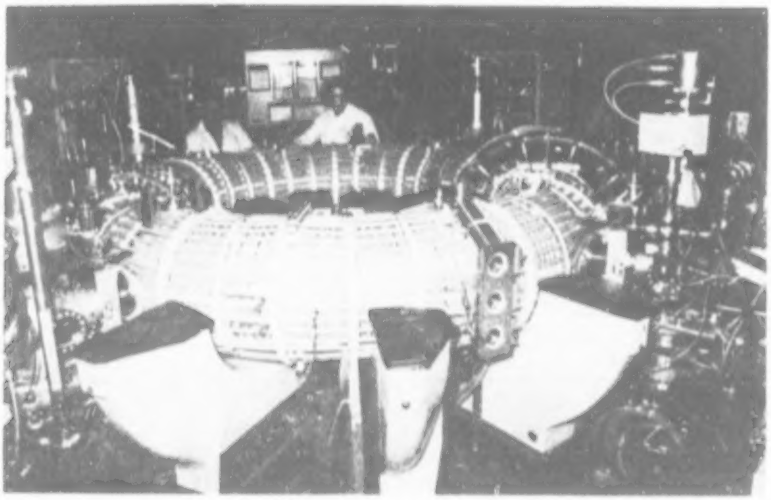


Fig. 68 ZT-40 during assembly.

z pinch: similar to a theta pinch but the magnetic field encircles the axis of a cylindrical column.

ZT-40 device: an experiment at LASL designed to investigate the properties of the MHD stable reversed-field pinch confinement approach to magnetic fusion. The object is to determine the physics of the formation, heating, and transport needed to design future scaled-up experiments leading to the fusion reactor goal. [Figs. 67, 68]

Z value: See **atomic number**.

FISCAL YEAR 1983 DEPARTMENT OF ENERGY BUDGET REVIEW

WEDNESDAY, MARCH 24, 1982

House of Representatives,
Committee on Science and Technology,
Subcommittee on Energy Research and Production,
Washington, D.C.

The subcommittee met, pursuant to recess, at 9:03 a.m., in room 2325, Rayburn House Office Building, Hon. Marilyn Lloyd Bouquard (chairman of the subcommittee) presiding.

Present: Representatives Bouquard, Young, Volkmer, Lowery, and Hollenbeck.

Staff present: Harlan Watson, technical consultant; Louis Ventre, counsel; Joyce Freiwald, Republican technical consultant; Lee Wallace, Republican energy director.

Mrs. Bouquard. The subcommittee will come to order.

Good morning, ladies and gentlemen. Today the subcommittee will continue its review of the Department of Energy's fiscal year 1983 budget request for the magnetic fusion energy program. We will be receiving testimony from two panels of industry representatives and other interested parties of the fusion community, including our old friend and former chairman, Mike McCormack. It is certainly good to have you back with us today, Mike. And we are also happy to have Mr. Ed Kintner, who is former Associate Director of the Office of Fusion Energy. We welcome you, also, Ed.

Yesterday, if you were not here, we heard from the Department of Energy folks. I found their testimony to be both heartening and at the same time rather discouraging. We are promised much in the way of potential breakthroughs in fusion energy if only sufficient funding were available for us to move forward.

And yet, DOE, because of a variety of pressures, refuses to request the money they need to get the job done. The administration's attitude reminds me of a friend of mine that once asked me if I was hungry. When I said yes, she said, "Well, you know, if I had some eggs, we could have some ham and eggs, if I had some ham." [Laughter.]

We are very interested in hearing outside assessments of the program and receiving their input on what direction they think the national program should be heading.

In a very short time, I am going to be turning the proceedings over to Congressman Bob Young of Missouri. Congressman Young has been most supportive of the program and very instrumental in that he has made it a point to visit the major fusion facilities over the past year to encourage the DOE to emphasize a greater role for industry.

Bob, it has certainly been a pleasure to work with you on the subcommittee, and at this time I am turning the proceedings over to you.

Just one thing. I do ask unanimous consent that, pursuant to House rules, television and other recordings of today's hearings be permitted, without objection.

Without objection, it is so ordered.

Mr. YOUNG. Thank you, Madam Chairman.

Good morning, ladies and gentlemen. I am Congressman Bob Young of Missouri, and I will be chairing the remainder of today's hearings at the request of Chairman Bouquard.

As Mrs. Bouquard has stated earlier, today the subcommittee will be hearing testimony from the interested members of industry and the fusion community. We look forward to hearing from this group's assessment of the program's technical readiness to move into a significant engineering development phase. We want to know if their faith in the readiness of the program to move ahead has remained unshaken.

We also want to examine the roles that the industrial, national laboratory, and university communities are to play is we are to continue to move forward. This committee, as Chairman Bouquard noted in her testimony yesterday, is particularly interested in involving industry in a significant role as soon as possible.

Our witnesses will be appearing today in a panel format. Our first panel will be composed of Mr. Kenneth Matson, Dr. Tihiro Ohkawa, accompanied by Dr. John Gilleland, and Dr. Dominic Repici.

Mr. Matson is vice president of the Public Service Electric and Gas Research Corp. He is also a member of the Atomic Industrial Forum's Committee on Fusion. He will be speaking on behalf of the Atomic Industrial Forum.

Dr. Ohkawa is vice president for fusion and advanced technology at the General Atomic Co. He is accompanied by Dr. John Gilleland, director of the Doublet III project. Dr. Ohkawa will be appearing in place of Dr. Harold Agnew, president of General Atomic Co., who was unable to attend today's hearing.

Dr. Dominic Repici is director of corporate development of INESCO, Inc. Dr. Repici is testifying in the place of Dr. Robert Bussard, president of INESCO, who has been detained in California and is unable to be here today. Dr. Repici is familiar to a number of the members of the subcommittee for his good work at OMB.

I would like to welcome all of you here today. I would ask that each of you give your testimony in turn, and then we will ask you questions after you have finished.

Mr. Matson, would you care to proceed, sir?

STATEMENT OF KENNETH MATSON, VICE PRESIDENT, PUBLIC SERVICE ELECTRIC & GAS RESEARCH CORP., ON BEHALF OF THE ATOMIC INDUSTRIAL FORUM

Mr. **Matson**. Good morning, Mrs. Bouquard, Chairman Young. It is a pleasure to be here this morning to address the committee on fusion.

The Atomic Industrial Forum is a trade association with over 600 member organizations. More than 100 of the member organizations are outside the United States—in Europe, South America, and the Far East. All of the organizations share a dedication to the peaceful use of nuclear energy for mankind's needs in energy, medicine, and industrial development.

The member organizations include electric utilities, architect-engineers, equipment manufacturers, mining and milling companies, labor unions, laboratories, financial institutions, and universities.

First, let me thank you for this opportunity to present the views of the AIF Committee on the Fusion program and its proposed budget for fiscal year 1983.

The AIF's Committee on Fusion has followed the development of fusion power since 1975 and has testified before this and other committees of the Congress.

In 1979, the AIF committee reviewed the fusion program to examine how industrial participation could be brought about in a timely and orderly way. A copy of the report summarizing the findings was entered into the record of hearings of your subcommittee on July 28, 1980. The review addressed the basic problems of providing policy and institutional continuity to a program in which the energy payoffs will not be realized for several decades.

The AIF committee found that the scientific evidence was sufficiently in hand for magnetic fusion to proceed to engineering technology development. This will necessitate, as was recognized in the Magnetic Fusion Engineering Act of 1980, expansion of the program to encompass an engineering and technology development effort.

Last year, the AIF committee examined the organizational and management issues inherent in proceeding with such an effort. That report, which was entered into the hearing record of your subcommittee on March 3, 1981, recognized that proceeding with a parallel engineering phase will require a cooperative interaction from all sectors—the national laboratories, universities, and especially industry.

It concluded that those concerned with marketplace factors should be involved in the early stages of technological development. This, in turn, should be oriented from the outset to a goal of commercialization.

The establishment of a Center for Fusion Engineering was viewed as a critical step in the pursuit of this goal. The AIF committee has reviewed this conclusion in light of the prospective budgetary limitations and has found that the recommendation to establish a Center for Fusion Engineering remains valid.

We believe that such a center, however small its initial budget, is an appropriate vehicle for beginning engineering and technological development under industrial leadership.

There are a number of clarifying points I would like to offer in support of this recommendation: The $9 million line item for a Center for Fusion Engineering in fiscal year 1982 and the $5 million proposed in fiscal year 1983 for operating expenses to support activities related to a Center for Magnetic Fusion Engineering would supports its establishment.

The Center for Fusion Engineering should be given responsibilities for focusing the thrust of near-term engineering objectives toward the end goal of commercialization. This includes involving industry in planning and setting technical direction. The Center should also be responsible for coordinating all DOE magnetic fusion engineering technology programs currently underway; evaluating existing research devices for upgrading to provide an earlier and less expensive input for the engineering data base; developing the conceptual design of the next magnetic confinement device following TFTR to satisfy principal physics and engineering objectives; and conducting engineering testing in relevant test facilities to begin developing an engineering data base. Industry has available a wide range of test facilities, particularly those previously developed for nuclear and aerospace technologies, which could be effectively used for this purpose.

Effective organization and management of an engineering effort are critical to solving the complex problems inherent in taking a technology which has yet to emerge from the laboratory and advancing it to engineering practice. The establishment of an organization which has engineering development and industrial integration as its charter is an essential first step.

The AIF committee recognizes that progress in magnetic fusion development is currently limited by available funds rather than technical barriers. For the program to move ahead at a pace that would establish, at the earliest possible time, its potential as a commercial energy option would require at least an additional $100 million in fiscal year 1983.

Budget realities preclude this level of funding and lead to a more critical issue: Will $444 million in fiscal year 1983 prove adequate to sustain the program at a level that will permit effective utilization of increased funding when the economy can support it? The answer is not clear, but it would appear that the fiscal year 1982 level of $454 million is the barest minimum for maintaining the basic direction of the fusion program in fiscal year 1983.

Of even more concern is the change in fusion program direction inherent in the proposed 1983 budget. For some years, it has been the consensus of the fusion community that other confinement technologies may prove to be superior to the tokamak. For this reason, the mirror and elmo bumpy torus programs were being developed to provide possible alternatives as well as comparative evaluation.

This consensus was supported in the report of the Fusion Review Panel of the Energy Research Advisory Board, chaired by S. J. Buchsbaum, as well as in an earlier report of ad hoc experts in fusion chaired by John Foster.

Delaying the development of alternative confinement systems relative to tokamak development could be a major mistake if one of the alternate technologies should prove to be superior.

The austere budget can and perhaps should be accepted until the state of the economy improves. It should not, however, be used as the rationale for changing the basic direction of the fusion program.

This concludes my prepared remarks, and I would be pleased to answer your questions.

Mr. Young. Thank you very much, Mr. Matson.

[The prepared statement of Mr. Matson follows:]

ATOMIC INDUSTRIAL FORUM
COMMITTEE ON FUSION
TESTIMONY BY KENNETH L. MATSON
BEFORE THE SUBCOMMITTEE ON ENERGY RESEARCH AND PRODUCTION
OF THE COMMITTEE ON SCIENCE AND TECHNOLOGY
U.S. HOUSE OF REPRESENTATIVES
MARCH 24, 1982

THANK YOU, MADAM CHAIRMAN. I AM KENNETH L. MATSON, VICE PRESIDENT OF PSE&G RESEARCH CORPORATION, A WHOLLY-OWNED SUBSIDIARY OF PUBLIC SERVICE ELECTRIC AND GAS COMPANY, HEADQUARTERED IN NEWARK, NEW JERSEY. I AM ALSO A MEMBER OF THE ATOMIC INDUSTRIAL FORUM'S COMMITTEE ON FUSION, AND IT IS IN THAT CAPACITY THAT I AM APPEARING BEFORE YOU TODAY.

THE ATOMIC INDUSTRIAL FORUM IS A TRADE ASSOCIATION WITH OVER 600 MEMBER ORGANIZATIONS. MORE THAN 100 OF THE MEMBER ORGANIZATIONS ARE OUTSIDE THE U.S.--IN EUROPE, SOUTH AMERICA, AND THE FAR EAST. ALL OF THE ORGANIZATIONS SHARE A DEDICATION TO THE PEACEFUL USE OF NUCLEAR ENERGY FOR MANKIND'S NEEDS IN ENERGY, MEDICINE, AND INDUSTRIAL DEVELOPMENT. THE MEMBER ORGANIZATIONS INCLUDE ELECTRIC UTILITIES, ARCHITECT-ENGINEERS, EQUIPMENT MANUFACTURERS, MINING AND MILLING COMPANIES, LABOR UNIONS, LABORATORIES, FINANCIAL INSTITUTIONS, AND UNIVERSITIES.

FIRST, LET ME THANK YOU FOR THIS OPPORTUNITY TO PRESENT THE VIEWS OF THE AIF COMMITTEE ON THE FUSION PROGRAM AND ITS PROPOSED BUDGET FOR FISCAL YEAR 1983.

THE AIF'S COMMITTEE ON FUSION HAS FOLLOWED THE DEVELOPMENT OF FUSION POWER SINCE 1975 AND HAS TESTIFIED BEFORE THIS AND OTHER COMMITTEES OF THE CONGRESS.

IN 1979 THE AIF COMMITTEE REVIEWED THE FUSION PROGRAM TO EXAMINE HOW INDUSTRIAL PARTICIPATION COULD BE BROUGHT ABOUT IN A TIMELY AND ORDERLY WAY. A COPY OF THE REPORT SUMMARIZING THE FINDINGS WAS ENTERED INTO THE RECORD OF HEARINGS OF YOUR SUBCOMMITTEE ON JULY 28, 1980. THE REVIEW ADDRESSED THE BASIC PROBLEMS OF PROVIDING POLICY AND INSTITUTIONAL CONTINUITY TO A PROGRAM IN WHICH THE ENERGY PAYOFFS WILL NOT BE REALIZED FOR SEVERAL DECADES.

THE AIF COMMITTEE FOUND THAT THE SCIENTIFIC EVIDENCE WAS SUFFICIENTLY IN HAND FOR MAGNETIC FUSION TO PROCEED TO ENGINEERING TECHNOLOGY DEVELOPMENT. THIS WILL NECESSITATE, AS WAS RECOGNIZED IN THE MAGNETIC FUSION ENGINEERING ACT OF 1980, EXPANSION OF THE PROGRAM TO ENCOMPASS AN ENGINEERING AND TECHNOLOGY DEVELOPMENT EFFORT.

LAST YEAR, THE AIF COMMITTEE EXAMINED THE ORGANIZATIONAL AND MANAGEMENT ISSUES INHERENT IN PROCEEDING WITH SUCH AN EFFORT. THAT REPORT, WHICH WAS ENTERED INTO THE HEARING RECORD OF YOUR SUBCOMMITTEE ON MARCH 3, 1981, RECOGNIZED THAT PROCEEDING WITH A PARALLEL ENGINEERING PHASE WILL REQUIRE A COOPERATIVE INTERACTION FROM ALL SECTORS--THE NATIONAL LABORATORIES, UNIVERSITIES, AND ESPECIALLY INDUSTRY. IT CONCLUDED THAT THOSE CONCERNED WITH MARKETPLACE FACTORS SHOULD BE INVOLVED IN THE EARLY STAGES OF TECHNOLOGICAL DEVELOPMENT. THIS, IN TURN, SHOULD BE ORIENTED FROM THE OUTSET TO A GOAL OF COMMERCIALIZATION. THE ESTABLISHMENT OF A CENTER FOR FUSION ENGINEERING WAS VIEWED AS A CRITICAL STEP IN PURSUIT OF THIS GOAL. THE AIF COMMITTEE HAS REVIEWED THIS

CONCLUSION IN LIGHT OF THE PROSPECTIVE BUDGETARY LIMITATIONS, AND HAS FOUND THAT THE RECOMMENDATION TO ESTABLISH A CENTER FOR FUSION ENGINEERING REMAINS VALID.

WE BELIEVE THAT SUCH A CENTER, HOWEVER SMALL ITS INITIAL BUDGET, IS AN APPROPRIATE VEHICLE FOR BEGINNING ENGINEERING AND TECHNOLOGICAL DEVELOPMENT UNDER INDUSTRIAL LEADERSHIP.

THERE ARE A NUMBER OF CLARIFYING POINTS I WOULD LIKE TO OFFER IN SUPPORT OF THIS RECOMMENDATION:

- THE $9 MILLION LINE ITEM FOR A CENTER FOR FUSION ENGINEERING IN FISCAL YEAR 1982 AND THE $5 MILLION PROPOSED IN FISCAL YEAR 1983 OPERATING EXPENSES TO SUPPORT ACTIVITIES RELATED TO A CENTER FOR MAGNETIC FUSION ENGINEERING WOULD SUPPORT ITS ESTABLISHMENT.
- THE CENTER FOR FUSION ENGINEERING SHOULD BE GIVEN RESPONSIBILITIES FOR:
  - FOCUSING THE THRUST OF NEAR-TERM ENGINEERING OBJECTIVES TOWARD THE END GOAL OF COMMERCIALIZATION. THIS INCLUDES INVOLVING INDUSTRY IN PLANNING AND SETTING TECHNICAL DIRECTION.
  - COORDINATING ALL DOE MAGNETIC FUSION ENGINEERING TECHNOLOGY PROGRAMS CURRENTLY UNDERWAY.
  - EVALUATING EXISTING RESEARCH DEVICES FOR UPGRADING TO PROVIDE AN EARLIER AND LESS EXPENSIVE INPUT FOR THE ENGINEERING DATA BASE.
  - DEVELOPING THE CONCEPTUAL DESIGN OF THE NEXT MAGNETIC CONFINEMENT DEVICE FOLLOWING TFTR. TO SATISFY PRINCIPAL PHYSICS AND ENGINEERING OBJECTIVES.

- CONDUCTING ENGINEERING TESTING IN RELEVANT TEST FACILITIES TO BEGIN DEVELOPING AN ENGINEERING DATA BASE. INDUSTRY HAS AVAILABLE A WIDE RANGE OF TEST FACILITIES, PARTICULARLY THOSE PREVIOUSLY DEVELOPED FOR NUCLEAR AND AEROSPACE TECHNOLOGIES, WHICH COULD BE EFFECTIVELY USED FOR THIS PURPOSE.

EFFECTIVE ORGANIZATION AND MANAGEMENT OF AN ENGINEERING EFFORT ARE CRITICAL TO SOLVING THE COMPLEX PROBLEMS INHERENT IN TAKING A TECHNOLOGY WHICH HAS YET TO EMERGE FROM THE LABORATORY AND ADVANCING IT TO ENGINEERING PRACTICE. THE ESTABLISHMENT OF AN ORGANIZATION WHICH HAS ENGINEERING DEVELOPMENT AND INDUSTRIAL INTEGRATION AS ITS CHARTER IS AN ESSENTIAL FIRST STEP.

THE AIF COMMITTEE RECOGNIZES THAT PROGRESS IN MAGNETIC FUSION DEVELOPMENT IS CURRENTLY LIMITED BY AVAILABLE FUNDS RATHER THAN TECHNICAL BARRIERS. FOR THE PROGRAM TO MOVE AHEAD AT A PACE THAT WOULD ESTABLISH AT THE EARLIEST POSSIBLE TIME ITS POTENTIAL AS A COMMERCIAL ENERGY OPTION WOULD REQUIRE AT LEAST AN ADDITIONAL $100 MILLION IN FISCAL YEAR 1983. BUDGET REALITIES PRECLUDE THIS LEVEL OF FUNDING AND LEAD TO A MORE CRITICAL ISSUE: WILL $444 MILLION IN FISCAL YEAR 1983 PROVE ADEQUATE TO SUSTAIN THE PROGRAM AT A LEVEL THAT WILL PERMIT EFFECTIVE UTILIZATION OF INCREASED FUNDING WHEN THE ECONOMY CAN SUPPORT IT? THE ANSWER IS NOT CLEAR, BUT IT WOULD APPEAR THAT THE FY 82 LEVEL OF $454 MILLION IS THE BAREST MINIMUM FOR MAINTAINING THE BASIC DIRECTION OF THE FUSION PROGRAM IN FY 83.

OF EVEN MORE CONCERN IS THE CHANGE IN FUSION PROGRAM DIRECTION INHERENT IN THE PROPOSED 1983 BUDGET. FOR SOME YEARS, IT HAS BEEN THE CONSENSUS OF THE FUSION COMMUNITY THAT OTHER CONFINEMENT TECHNOLOGIES MAY PROVE TO BE SUPERIOR TO THE TOKAMAK. FOR THIS REASON THE MIRROR AND ELMO BUMPY TORUS PROGRAMS WERE BEING DEVELOPED TO PROVIDE POSSIBLE ALTERNATIVES AS WELL AS COMPARATIVE EVALUATIONS. THIS CONSENSUS WAS SUPPORTED IN THE REPORT OF THE FUSION REVIEW PANEL OF THE ENERGY RESEARCH ADVISORY BOARD, CHAIRED BY S.J. BUCHSBAUM AS WELL AS IN AN EARLIER REPORT OF AD HOC EXPERTS IN FUSION CHAIRED BY JOHN FOSTER. DELAYING THE DEVELOPMENT OF ALTERNATIVE CONFINEMENT SYSTEMS RELATIVE TO TOKAMAK DEVELOPMENT COULD BE A MAJOR MISTAKE IF ONE OF THE ALTERNATE TECHNOLOGIES SHOULD PROVE TO BE SUPERIOR.

THE AUSTERE BUDGET CAN AND PERHAPS SHOULD BE ACCEPTED UNTIL THE STATE OF THE ECONOMY IMPROVES. IT SHOULD NOT, HOWEVER, BE USED AS THE RATIONALE FOR CHANGING THE BASIC DIRECTION OF THE FUSION PROGRAM.

THIS CONCLUDES MY PREPARED REMARKS. I WOULD BE PLEASED TO ANSWER YOUR QUESTIONS.

Mr. YOUNG. Dr. Ohkawa?

STATEMENT OF TIHIRO OHKAWA, VICE PRESIDENT FOR FUSION AND ADVANCED TECHNOLOGY, GENERAL ATOMIC CO., ACCOMPANIED BY JOHN GILLELAND, DIRECTOR, DOUBLET III PROJECT

Dr. OHKAWA. Mr. Chairman, I am Tihiro Ohkawa, vice president for fusion and advanced technology at the General Atomic Co., in San Diego, Calif.

Dr. Agnew is unable to be here today. He sends his regrets and has asked me to testify in his place.

I am joined by Dr. John Gilleland, on my right, director of the Doublet III program at General Atomic.

We thank you for the opportunity to present testimony regarding the General Atomic fusion program. I would first like to comment on the fusion budget as a whole.

Some Government officials have been saying that fusion won't be here for 50 or even 70 years. This sort of unwarranted pessimism can easily become a self-fulfilling prophecy. If the Nation does not fund it, it will not be achieved. Fusion will recede into a distant future, and a future without the freedom from energy strangulation is indeed a bleak one.

Based on sound scientific and technological judgment, fusion is ready for the transition from the experimental phase to the reactor phase. The fusion program has the technology, the organization, and the expertise in the appropriate disciplines to make that transition effectively.

We have been an enthusiastic supporter of the Magnetic Fusion Engineering Act of 1980. I hope that economic conditions would improve soon so that we can begin the activities envisioned in that act.

The Nation's fusion program could effectively use more funding than you are contemplating here in order to develop fusion power as fast as technical bases permit and to stay competitive within the world fusion program.

Given a limited budget, we support the President's budget as a well balanced one. Other witnesses, too, have spoken about the national fusion program, its progress, and its needs. We at General Atomic share their point of view.

I would now like to ask Dr. Gilleland to describe our work at General Atomic and illustrate how our program fits into the national program.

[The prepared statment of Dr. Ohkawa follows:]

STATEMENT OF DR. TIHIRO OHKAWA, VICE PRESIDENT OF FUSION AND ADVANCED TECHNOLOGY

Madame Chairman, I am Tihiro Ohkawa, Vice President for Fusion and Advanced Technology at General Atomic Company in San Diego, California. Dr. Agnew is unable to be here today. He sends his regrets and has asked me to testify in his place. I am joined by Dr. John Gilleland, Director of the Doublet III program at GA. We thank you for the opportunity to present testimony regarding the General Atomic fusion program.

I first want to comment on the fusion budget as a whole. Some government officials have been saying that fusion won't be here for fifty or even seventy years. This sort of unwarranted pessimism can easily become a selffulfilling prophecy. If the nation doesn't fund it, it will not be achieved—fusion will recede into the future, and a future without the freedom from energy strangulation that fusion can provide may well be a bleak one. The community is ready for the transition from the experimental phase to the reactor phase. We have the technology, the organizations, and the expertise in the appropriate disciplines to make that transition smoothly.

We have been enthusiastic supporters of the Magnetic Fusion Engineering Act of 1980. I hope that economic conditions will improve soon, so that we can begin the activities envisioned in the Act. The nation's fusion program could effectively use more funding than you are contemplating here in order to stay competitive within the world fusion program. Given a limited budget, we support the President's budget as a well balanced one. Other witnesses too have spoken about the national fusion program, its progress and its needs. We at General Atomic share their point of view.

I would now like to ask Dr. Gilieland to describe our work at GA and illustrate how it fits into the national program.

Mr. YOUNG. Dr. Gilleland?

Dr. GILLELAND. In 1957, General Atomic became the first private institution to engage in fusion research. That program of research has been rich and diverse and has continued until today.

Our fusion program has been supported in recent years primarily through the Department of Energy, but from the beginning, it has also received support from utilities and from the company itself. This breadth of support is both a result and a reflection of General Atomic's unique position in fusion energy development.

We are participants in the forefront of fusion research but, as an industrial company, we concentrate on and are a bridge to the commercialization of fusion power.

The cornerstone of our program is Doublet III, the largest operating tokamak in the world. Doublet III has the goal of approximating the physical conditions in a confined plasma that will be necessary for a fusion reactor.

Two years ago, the Japanese Atomic Energy Research Institute, JAERI, joined the Department of Energy in a cooperative research program on Doublet III. This 5-year cooperation represents a strong international endorsement of our national program and General Atomic's program. It provides Japanese funding for much of the basic hardware fundamental to Doublet III's long-range research plans.

This cooperative venture has also resulted in an enhancement of scientific productivity because of the unusual mix of scientific methods and personnel represented by the combination of Japanese and American scientists now present in LaJolla.

Their collective efforts are resulting in the experimental verification of several propositions that are important for the future of the tokamak as a viable and very attractive reactor.

Doublet III is a large tokamak. It is capable of accommodating large, highly shaped plasmas, plasmas the size of those planned for Princeton's TFTR and Japan's JT-60. Doublet III is unique in that it combines physical ruggedness with an unusually high degree of technical sophistication and experimental flexibility.

These features of the machine are fully utilized in Doublet III's long-range experimental program plan. This plan may be visualized as having three overlapping but distinct phases.

Phase I began in 1978 after the completion of Doublet III, slightly ahead of the schedule first set in late 1973. In this first phase, experiments were conducted which emphasized plasma shaping and control and ohmically heated discharges.

We verified our ability to make and retain a variety of plasma shapes, confirmed predictions about how well the magnetic bottle will contain plasma heat as a function of its shape and size, and demonstrated methods for prevention of plasma poisoning by impurities.

These results added greatly to our confidence in the choice of elongated D-shaped plasmas for the first generation tokamak reactor, gave experimental validity to the simplified impurity control schemes adopted for fusion reactor designs, and provided the technical basis for the final phases of experimentation on Doublet III.

The second phase of Doublet III operation recently began in January of this year and will continue well into fiscal 1984. During this period, increasing levels of neutral beam heating power will be installed, thus allowing us to heat the plasma well beyond the temperatures attained in the first phase, phase I.

Initial tests of radio frequency systems for plasma heating and plasma current drive will also be conducted. Particular emphasis will be placed on maximizing beta. Beta is an entity which describes, in a certain sense, the relative power density of a plasma. More formally, beta is the ratio of the plasma pressure to magnetic field pressure in a fusion device. Beta is one of the important indices of reactor performance. In a sense, it tells one how much power one is going to be able to get out of a reactor or to give an investment in the system.

A tokamak reactor needs to operate with a beta above 4½ to 5 percent. Beta values well over 2 percent, perhaps approaching 2½ percent, have been achieved in Doublet III, utilizing only the first of three neutral beam heaters scheduled for installation.

Thus, these preliminary results are very encouraging, and we are confident that the additional heating will allow us to reach reactor-like beta values.

Preparations for phase III of the Doublet III program have begun. In phase III, Doublet III's existing vacuum vessel will be replaced by a larger one in late fiscal 1984. This will be a relatively easy task, since Doubtlet III was designed from the beginning to accommodate a new vacuum vessel with a minimum of disassembly and assembly effort. Its larger, D-shaped plasma should have even better confinement properties and should more closely resemble a reactor plasma in size and operating conditions.

A new vessel will allow the high beta plasma results to be extended to a regime of higher temperature characteristic of fusing plasmas. Plasma engineering problems for reactor design can then be addressed directly.

In summary, nature has been kind to us lately. The experimental results have been quite favorable. We have been quite fortunate at General Atomic in that we have made our eight program milestones which were set up for us during the last year.

We are proceeding with preparations to install a new vacuum vessel in Doublet III, and we are thus taking advantage of a unique opportunity to build and operate a device that fulfills the program's need for a large D-shaped high current, high beta plasma.

Because of its engineering power and similarity in design philosophy to plans for first generation tokamak reactors, the modified Doublet III can be the primary program resource for elucidating the properties of our fusion reactor core. Moreover, it will provide an early test bed for future fusion engineering technologies.

I want to emphasize that this will be fully complementary to Princeton's tokamak fusion test reactor, TFTR, which will probe the engineering and physics of a reacting fuel. Together, these two experiments can provide the basis for confident operation of tokamak reactors.

The fiscal 1983 budget contains funding for the new Doublet III, which represents a highly cost-effective means of constructing a vitally needed tokamak research facility without buying a new operating mortgage. I hope that this committee, whose interest in fusion has historically been keen and well founded, shares General Atomic's belief in fusion's importance to the Nation.

Although I have been asked to speak about Doublet III, I wish to express my personal hope that you will continue to be strong supporters of the fusion program as a whole.

Thank you very much.

Mr. YOUNG. Thank you, Dr. Gilleland.

[The prepared statement of Dr. Gilleland follows:]

Statement of Dr. John Gilleland, Director of Doublet III

Madame Chairman, General Atomic was the first private industry to engage in fusion research, beginning in 1957. Our fusion program has been supported in recent years primarily through the Department of Energy, but from the beginning it has also received support from the utility industries and from the company itself. This breadth of support is both a result and a reflection of GA's unique position in fusion energy development. We are participants in the very forefront of fusion research, but as an industrial company we concentrate on and are a bridge to the commercialization of fusion power. The cornerstone of our program is Doublet III, currently the largest operating tokamak—toroidal magnetic confinement machine—in the world. Doublet III has the goal of approximating the physical conditions in a confined plasma that will be necessary for a fusion reactor.

Two years ago, the Japan Atomic Energy Research Institute joined the Department of Energy in cooperative research on Doublet III. This five-year cooperation represents a strong international endorsement of our program and provides funding for much of the basic hardware fundamental to our long range research plans. This cooperative venture has also resulted in an enhancement of scientific productivity because of the unusual mix of scientific methods and manpower represented by the combination of Japanese and General Atomic scientists. Their collective efforts are resulting in the experimental verification of several theoretical propositions that are important for the future of the tokamak as a viable reactor.

Doublet III is a large tokamak capable of accommodating large, highly-shaped plasmas the size of those planned for Princeton's TFTR and Japan's JT-60. Doublet III is unique in that it combines technical ruggedness with an unusually high degree of technical sohpistication and experimental flexibility.

These features of the machine are fully utilized in Doublet III's long-range experimental program plan. This plan may be visualized as having three overlapping, but distinctly discernible phases. Phase I began in 1978 after the completion of Doublet III slightly ahead of a schedule first set in 1974. Experiments were conducted which emphasized plasma shaping and control in ohmically-heated discharges. During this first phase we verified our ability to make and retain a variety of plasma shapes, confirmed predictions about how well the magnetic bottle will contain plasma heat as a function of its shape and size, and demonstrated methods for prevention of plasma poisoning by impurities. These results added greatly to our confidence in the choice of dee-shaped plasmas for the first-generation tokamak reactor, gave experimental validity to the simplified impurity control schemes adopted for fusion reactor designs, and provided the technical basis for the final phases of experimentation on Doublet III.

The second phase of Doublet III operation recently began in January of 1982 and will continue well into fiscal 1984. During this period increasing levels of neutral beam heating power will be installed, thus allowing us to heat the plasma well beyond the temperatures attained in Phase I. Initial tests of rf systems for plasma heating and plasma current drive will also be conducted. Particular emphasis will be placed on maximizing beta, a term connoting the relative power density of the plasma. More formally, beta is defined as the ratio of plasma pressure to magnetic field pressure in a fusion device.

Beta values well over 2 percent have been achieved in Doublet III utilizing only the first of the three neutral beam heaters scheduled for installation. A tokamak reactor is expected to operate with beta values of about 5 percent. Thus these preliminary results are encouraging, and we believe the additional heating will allow us to reach reactor-like beta values.

Preparations for Phase III have begun. Doublet III's existing vacuum vessel will be replaced by a larger one in late 1984. This will be a relatively easy task, since Doublet III was designed from the beginning to accommodate a new vacuum vessel with a minimum of disassembly and assembly effort. It's larger, dee-shaped plasma should have even better confinement properties and should more closely resemble a reactor plasma in size and operating conditions. A new vessel will allow the high-beta plasma results to be extended to a regime of higher temperature characteristic of a fusing plasma. Engineering problems for reactor design can then be addressed directly.

We thus have a unique opportunity to build and operate a device that fills the need for a large, shaped, high-current, high-beta plasma. Owing to the flexibility of the Doublet III facility, and especially to the demountability of the toroidal field coils, this new stage can be initiated by a straightforward replacement of the present vacuum vessel with a large, dee-shaped vessel. Because of its engineering power and similarity in design philosophy to plans for first-generation tokamak reactors, the modified Doublet III can be the primary program resource for elucidating the properties of a fusion reactor core. Moreover, it will provide an early test bed for future fusion engineering technologies. It is fully complementary to Princeton's Tokamak Fusion Test Reactor, TFTR, which will probe the engineering and physics of a reacting fuel. Together, these two experiments can provide the basis for confident construction and operation of tokamak reactors.

The fiscal 1983 budget contains funding for the new vessel. It represents a highly cost-effective means of constructing a vitally needed tokamak research facility without buying a new operating mortgage.

I hope that this committee, whose interest in the fusion effort has historically been keen and well-informed, shares GA's belief in fusion's importance to the nation. I hope you will continue to be strong supporters of fusion energy. I thank you all, and we welcome any questions you may have.

Mr. YOUNG. Dr. Repici, would you care to proceed with your testimony?

STATEMENT OF DOMINIC J. REPICI, DIRECTOR OF CORPORATE DEVELOPMENT, INTERNATIONAL NUCLEAR ENERGY SYSTEMS

Dr. REPICI. Mr. Chairman, thank you.

Thank you very much, members of the committee. Dr. Bussard has asked me to send his apologies for not appearing here today. This does, however, give me the chance to appear and make some comments and depart somewhat from the record.

Let me say that it is a pleasure to be on this side of Pennsylvania Avenue and to shed some of the anonymity that covered what we have done prior to this appearance. It is a pleasure to be here and to state publicly that we support the goals of the act which this committee and the Congress passed 2 years ago, the McCormack Fusion Engineering Act.

I would like to depart from the general framework of the DOE program and make comments today about what INESCO is doing. We are a privately funded company, and we are outside the ambit of Federal funding. I would like to show some of the relationships that we have to the DOE program and to show where we are going.

The view from OMB and watching the transition between administration presents for me some unique impressions. There are issues of scope of the Federal involvement, the role of private industry, the relationships of private industry to the Federal fusion program, and the schedule of that program. I think those are probably best covered with this committee staff, and I would be glad to do that.

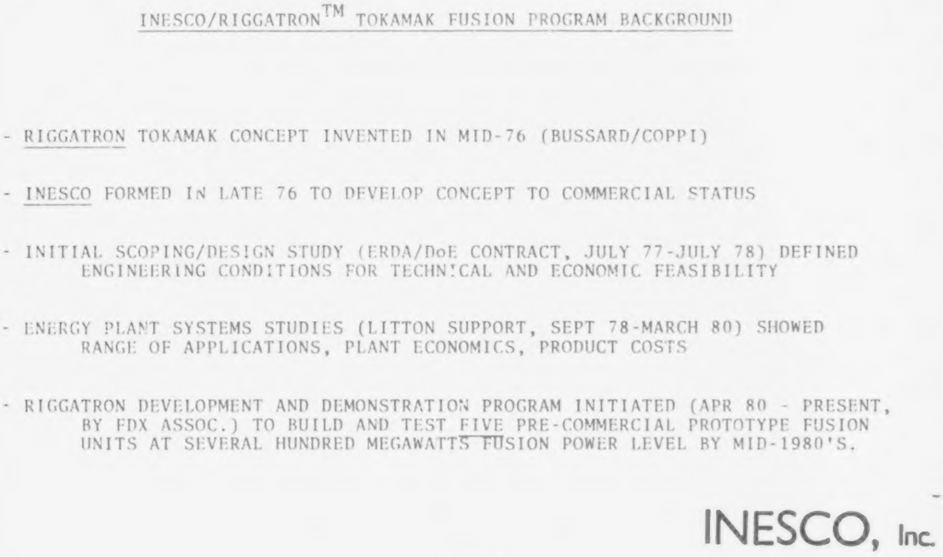
So I would like to confine my comments today to the INESCO program. There are four pieces which I would like to cover. Namely, I would like to say who we are and what our goals are. I want to say that practical fusion power, in our view, means that we must have small machines in some fashion. I would like to talk about the development program in which we hope, in 5 to 6 years, to actually have a burning plasma in a small demonstrated machine.

Then, briefly, I would like to touch upon the economic impacts that this would have on this country and on INESCO.

First, I think, if I may start with who we are, and just briefly a little bit of history. INESCO was founded in 1976. Dr. Bruno Coppi from MIT and Dr. Robert Bussard essentially each had half of an interesting idea. Dr. Coppi recognized that one could achieve ignition in small machines, and Dr. Bussard recognized that if one inverted the geometry by putting the neutron-absorbing mechanisms outside of the metal container, the copper magnets, one could extract energy.

At any rate, INESCO made a proposal to what was then the ERDA, and ERDA urged them to pursue the idea and funded this program for approximately 1 year.

I would like to use some viewgraphs so that I can skip through what is rather lengthy testimony and keep it to the confined time. I would like to start with slide 1.



INESCO/RIGGATRON™ TOKAMAK FUSION PROGRAM BACKGROUND

- RIGGATRON TOKAMAK CONCEPT INVENTED IN MID-76 (BUSSARD/COPPI)
- INESCO FORMED IN LATE 76 TO DEVELOP CONCEPT TO COMMERCIAL STATUS
- INITIAL SCOPING/DESIGN STUDY (ERDA/DoE CONTRACT, JULY 77-JULY 78) DEFINED ENGINEERING CONDITIONS FOR TECHNICAL AND ECONOMIC FEASIBILITY
- ENERGY PLANT SYSTEMS STUDIES (LITTON SUPPORT, SEPT 78-MARCH 80) SHOWED RANGE OF APPLICATIONS, PLANT ECONOMICS, PRODUCT COSTS
- RIGGATRON DEVELOPMENT AND DEMONSTRATION PROGRAM INITIATED (APR 80 - PRESENT, BY FDX ASSOC.) TO BUILD AND TEST FIVE PRE-COMMERCIAL PROTOTYPE FUSION UNITS AT SEVERAL HUNDRED MEGAWATTS FUSION POWER LEVEL BY MID-1980'S.

INESCO, Inc.

Slide 1

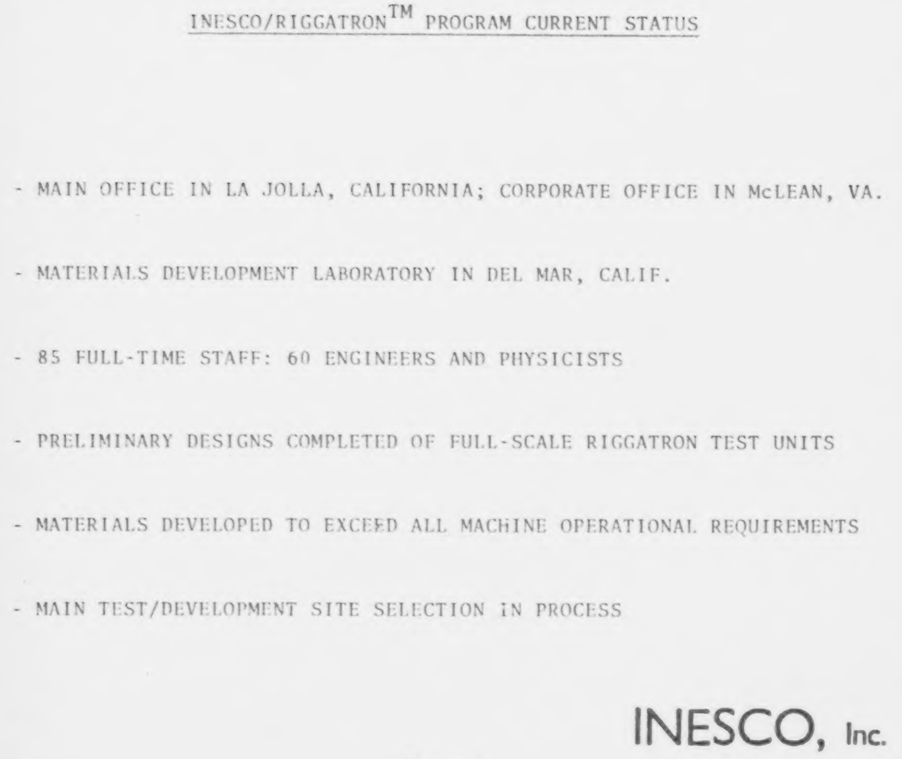
Essentially, the initial scoping/design study sponsored by ERDA showed the conditions that would be required for technical and economic feasibility of this device.

In the fall of 1978, after the completion of the ERDA work, Litton Industries supported INESCO for 18 months to conduct studies which were aimed at looking at what the markets would be for such a device if in fact we could build a device. So, in effect, it was a market scoping endeavor.

Some very phenomenal numbers come out of that, which I will share with you today, with the appropriate caveats.

In April of 1980, the RIGGATRON tokamak of the INESCO program was supported by FDX Associates, a Delaware limited partnership, which is funding INESCO at $102 million over a 5½ year period to literally build and test five of these precommercial prototype units.

The small units which we hope to build will have a fusion thermal power, of approximately 200 megawatts. It is a very substantial device. Next slide, please (slide 2).



INESCO/RIGGATRON^{TM} PROGRAM CURRENT STATUS

- MAIN OFFICE IN LA JOLLA, CALIFORNIA; CORPORATE OFFICE IN McLEAN, VA.
- MATERIALS DEVELOPMENT LABORATORY IN DEL MAR, CALIF.
- 85 FULL-TIME STAFF: 60 ENGINEERS AND PHYSICISTS
- PRELIMINARY DESIGNS COMPLETED OF FULL-SCALE RIGGATRON TEST UNITS
- MATERIALS DEVELOPED TO EXCEED ALL MACHINE OPERATIONAL REQUIREMENTS
- MAIN TEST/DEVELOPMENT SITE SELECTION IN PROCESS

INESCO, Inc.

Slide 2

The work conducted to date has resulted in a detailed design for our first fusion reactor. We have that in hand. We have successfully developed the basic materials needed to achieve that device. We have worked with the Brush-Wellman Co., Cabot-Berylco, and the International Copper Research Association to develop the coppers. The key uncertainty associated with this device is whether or not one can build the magnets.

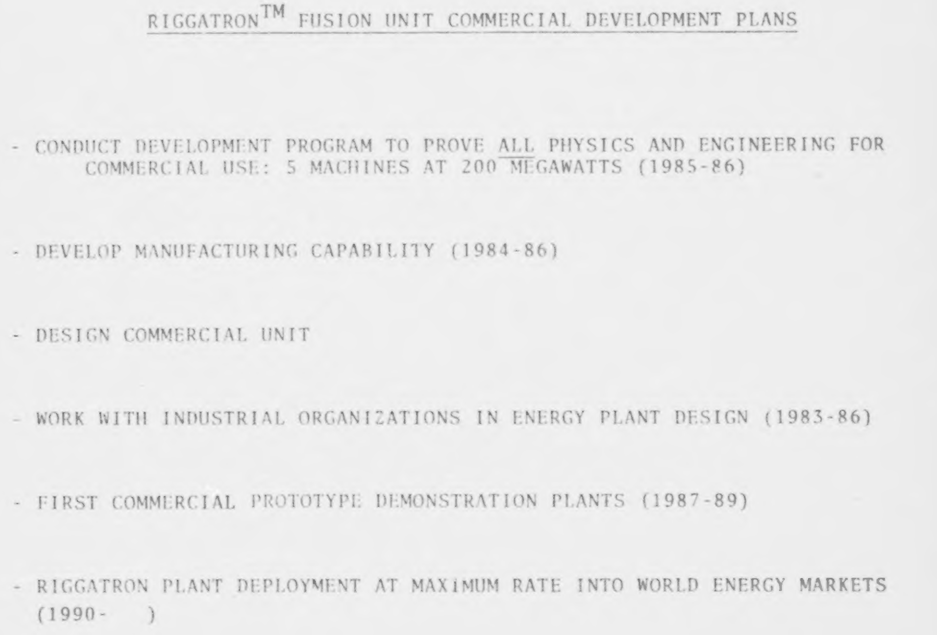
We have the materials in hand, and we are now engaged in the final site selection process. You should note that our work is based solidly on the world's tokamak research. It really represents an outgrowth of the MIT program, the Alcator program and the Frascati program. Quite candidly, we would not be here today were it not for the investment that this committee and this Congress have made in the U.S. fusion program.

We have not generated a new engineering technology, nor have we generated new confinement physics. Rather, we have taken the existing physics concepts and reengineered them, if you will, pushed them to the limits which the theory indicates they will go. In effect, we have reduced the size of tokamaks by a factor of about 1,000 in volume.

There remains a question of uncertainty, quite candidly, and that is whether or not tokamak confinement laws will still hold at the conditions needed for power reactors. That is a question, however, that is relevant to all tokamak research, not just what we are conducting.

We only have to go about a factor of two or three from the results shown in the fusion program to get to that ignition condition, so optimism is high.

Now, if some wholly unexpected or new phenomenon causes our tokamaks to fail, then, unfortunately, it is likely that all tokamaks would fail. This provides, from my perspective, a rationale for the breadth that the DOE program has at the present time. Next slide, please (slide 3).



RIGGATRON^{TM} FUSION UNIT COMMERCIAL DEVELOPMENT PLANS

- CONDUCT DEVELOPMENT PROGRAM TO PROVE ALL PHYSICS AND ENGINEERING FOR COMMERCIAL USE: 5 MACHINES AT 200 MEGAWATTS (1985-86)
- DEVELOP MANUFACTURING CAPABILITY (1984-86)
- DESIGN COMMERCIAL UNIT
- WORK WITH INDUSTRIAL ORGANIZATIONS IN ENERGY PLANT DESIGN (1983-86)
- FIRST COMMERCIAL PROTOTYPE DEMONSTRATION PLANTS (1987-89)
- RIGGATRON PLANT DEPLOYMENT AT MAXIMUM RATE INTO WORLD ENERGY MARKETS (1990-)

INESCO, Inc.

Slide 3

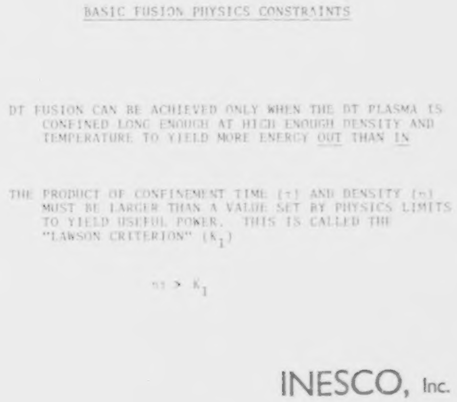
We are also engaged in the commercial development of this device. Clearly, we want to make a profit at this, and we are going to need manufacturing capability, and we hope to work with the major industrial organizations.

Next I would like to cover the basic concepts, why we must have small machines to be successful, to be economically successful. I will not go through the reassessment of what happens when fusion occurs, but the key point is that there are two criterea. We of course have to invest enough energy to heat the plasma so that the coulomb repulsion is overcome; literally, so that there is enough energy so that the ions can bump into each other and hence "stick" or fuse, if you will excuse the use of the vernacular.

Then, also, one has to achieve the Lawson criterion, which is essentially a statement that says the product of density and confinement time must equal some constant.

The amount of energy stored in the plasma is really a function of the number of particles per unit volume, and you need to have a magnetic field to put those particles in a bottle, quite literally. But, to control that plasma, you then have to invest energy in the magnetic field.

Could I have the next slide, please (slide 4)?



BASIC FUSION PHYSICS CONSTRAINTS

DT FUSION CAN BE ACHIEVED ONLY WHEN THE DT PLASMA IS CONFINED LONG ENOUGH AT HIGH ENOUGH DENSITY AND TEMPERATURE TO YIELD MORE ENERGY OUT THAN IN

THE PRODUCT OF CONFINEMENT TIME (τ) AND DENSITY (n) MUST BE LARGER THAN A VALUE SET BY PHYSICS LIMITS TO YIELD USEFUL POWER. THIS IS CALLED THE "LAWSON CRITERION" (K_1)

$n\tau > K_1$

INESCO, Inc.

SLIDE 4

The question then arises, what happens if we are limited in the strength of the magnetic field which we can produce? Well, the density that you can achieve is proportional to the magnetic field. Consequently, if you cannot have the necessary magnetic field, then you are limited as to what density you can achieve and, hence, you must have a larger resident time in the active region, that is, a larger confinement time, and, in effect, you must make the device larger.

Well, where does all this lead? May I have the next slide, please (slide 5)?

BASIC FUSION PHYSICS CONSTRAINTS

WITH SUPERCONDUCTING MAGNETS THE ATTAINABLE FIELDS (B) ARE TOO SMALL TO ALLOW SMALL MACHINES. THUS,

SUPERCONDUCTING MAGNET MACHINES MUST BE LARGE

LARGE SIZE MEANS LARGE COSTS AND LONG DEVELOPMENT TIMES
THIS IS THE SO-CALLED "MAINLINE" APPROACH

WITH COPPER MAGNETS, HIGH FIELDS CAN BE REACHED WHICH ALLOW SMALL SIZE, THUS

COPPER MAGNET MACHINES CAN BE SMALL

THIS IS THE INESCO/RIGGATRON TOKAMAK APPROACH

INESCO, Inc.

Slide 5

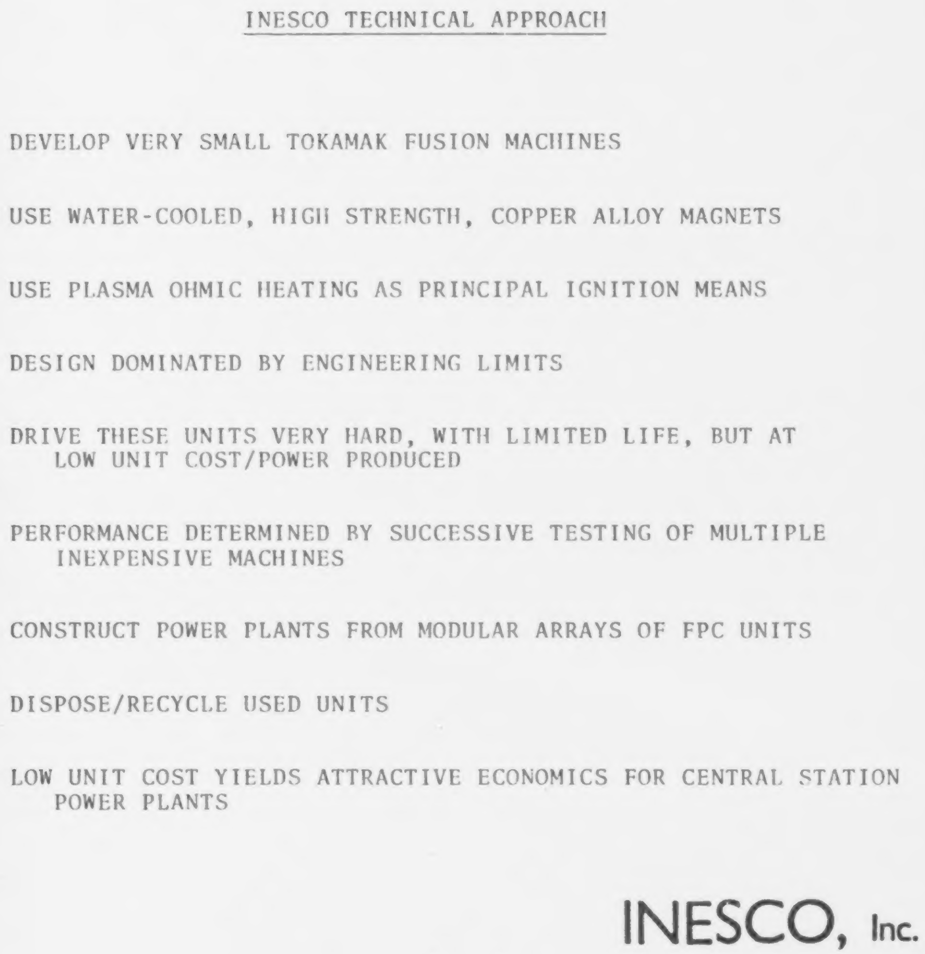
It says quite candidly, if you are going to use superconducting magnets, then the plasma region must be large, and if it is large, it is expensive and time consuming to develop and it generates a long-time scale for development.

The alternative upon which our program is based is to use copper magnets. They are smaller, they are less expensive, the development time is less; but there is a problem. You have to steal power from someplace to run those copper magnets. So there is really a question of power balance and whether or not you can physically build such magnet. These factors mitigate against copper. The alternative however, is superconductors; they are very complex. They are a new technology in many ways, and they must have large size.

What we are contending is that it is the small size—which is what our studies have shown, and it is quite straightforward—that it is the small size that generates the attractiveness of cost.

Let me now switch to the RIGGATRON tokamak development program and tell you what we are going to do. There are two pieces of fundamental engineering innovation that INESCO has produced. One of them is the fact that we are using water-cooled copper alloy conductors for the magnets. We feel we can build these magnets.

The second piece is that the blanket is outside of the magnets and, hence, the restrictions on blanket configuration are less severe. Our technical approach is shown in the next slide (slide 6.)



INESCO TECHNICAL APPROACH

DEVELOP VERY SMALL TOKAMAK FUSION MACHINES

USE WATER-COOLED, HIGH STRENGTH, COPPER ALLOY MAGNETS

USE PLASMA OHMIC HEATING AS PRINCIPAL IGNITION MEANS

DESIGN DOMINATED BY ENGINEERING LIMITS

DRIVE THESE UNITS VERY HARD, WITH LIMITED LIFE, BUT AT LOW UNIT COST/POWER PRODUCED

PERFORMANCE DETERMINED BY SUCCESSIVE TESTING OF MULTIPLE INEXPENSIVE MACHINES

CONSTRUCT POWER PLANTS FROM MODULAR ARRAYS OF FPC UNITS

DISPOSE/RECYCLE USED UNITS

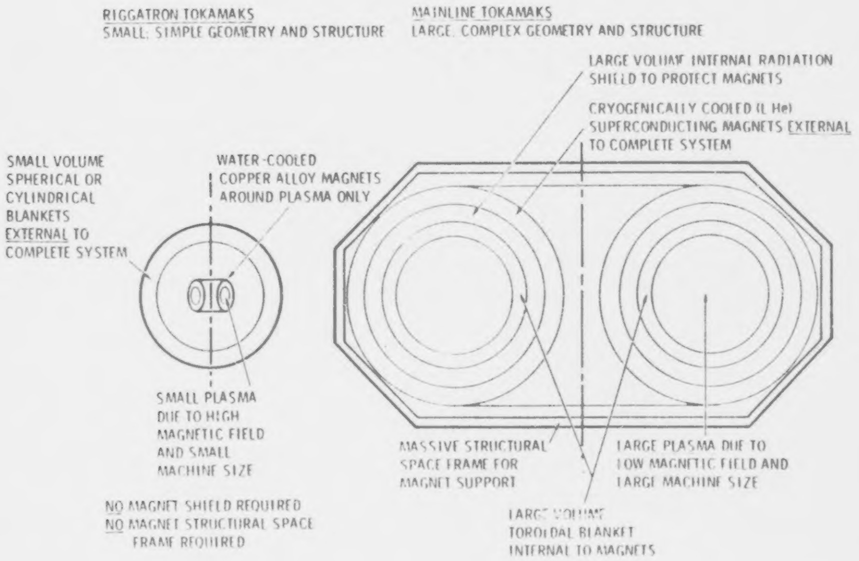
LOW UNIT COST YIELDS ATTRACTIVE ECONOMICS FOR CENTRAL STATION POWER PLANTS

INESCO, Inc.

Slide 6

The design philosophy that we are using is to design these machines to their engineering limits. They are small, about 8 tons' worth of copper. You can literally build, break and test them, and in effect you can push them to the limit, something you cannot do with larger machines. In a sense, we can reiterate the data and we can approach upon the problem literally by testing our way forward. Next slide, please (slide 7).

COMPARISON OF GEOMETRIC AND STRUCTURAL CHARACTERISTICS OF TOKAMAK FUSION OPTIONS

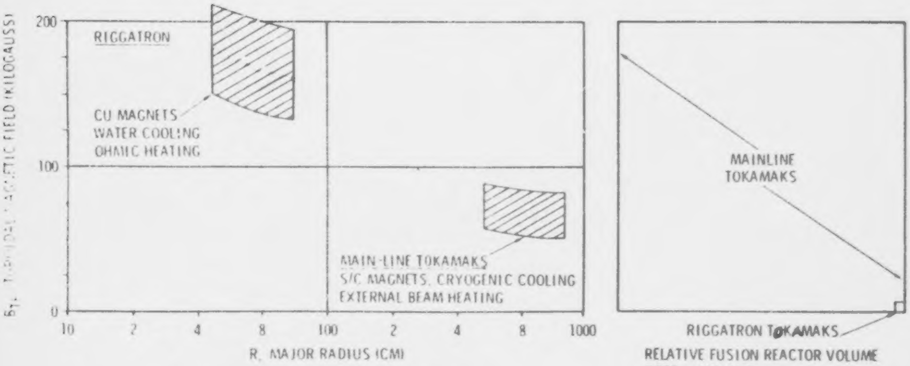

RIGGATRON TOKAMAKS
SMALL: SIMPLE GEOMETRY AND STRUCTURE
MAINLINE TOKAMAKS
LARGE, COMPLEX GEOMETRY AND STRUCTURE
LARGE VOLUME INTERNAL RADIATION SHIELD TO PROTECT MAGNETS
CRYOGENICALLY COOLED (L He) SUPERCONDUCTING MAGNETS EXTERNAL TO COMPLETE SYSTEM
SMALL VOLUME SPHERICAL OR CYLINDRICAL BLANKETS EXTERNAL TO COMPLETE SYSTEM
WATER-COOLED COPPER ALLOY MAGNETS AROUND PLASMA ONLY
SMALL PLASMA DUE TO HIGH MAGNETIC FIELD AND SMALL MACHINE SIZE
NO MAGNET SHIELD REQUIRED
NO MAGNET STRUCTURAL SPACE FRAME REQUIRED
MASSIVE STRUCTURAL SPACE FRAME FOR MAGNET SUPPORT
LARGE PLASMA DUE TO LOW MAGNETIC FIELD AND LARGE MACHINE SIZE
LARGE VOLUME TOROIDAL BLANKET INTERNAL TO MAGNETS

SLIDE 7

This is a comparison of the copper concepts with superconducting concepts. If you use the INESCO copper magnet concepts, you then can put the blanket outside of the device. If you are forced to use superconducting concepts, then you must have a large superconductor simply because of the magnetic field limitations on a superconductor.

You must then protect the superconductor. You must put the blanket or the mechanism by which you extract the neutrons within the superconductor, and that quite frankly makes for a difficult engineering problem and it makes for a big machine.

TECH APPROACHES TO TOKAMAK REACTORS RIGGATRON & MAINLINE TOKAMAKS



ALLOWABLE REGIMES FOR TOKAMAK OPERATION

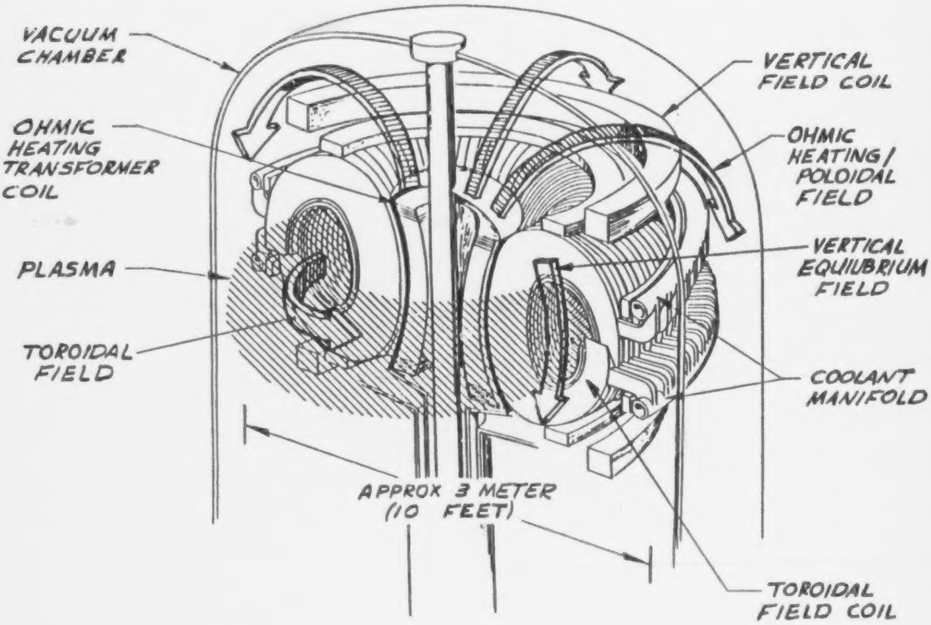
RELATIVE FUSION REACTOR VOLUME
COST ~ VOLUME

COMPARISON OF TECHNOLOGICAL FEATURES OF TOKAMAK FUSION OPTIONS

Slide 8

The next slide (slide 8) is just simply a quantification of what that means, just the different places where we are operating. Next slide, please (slide 9).

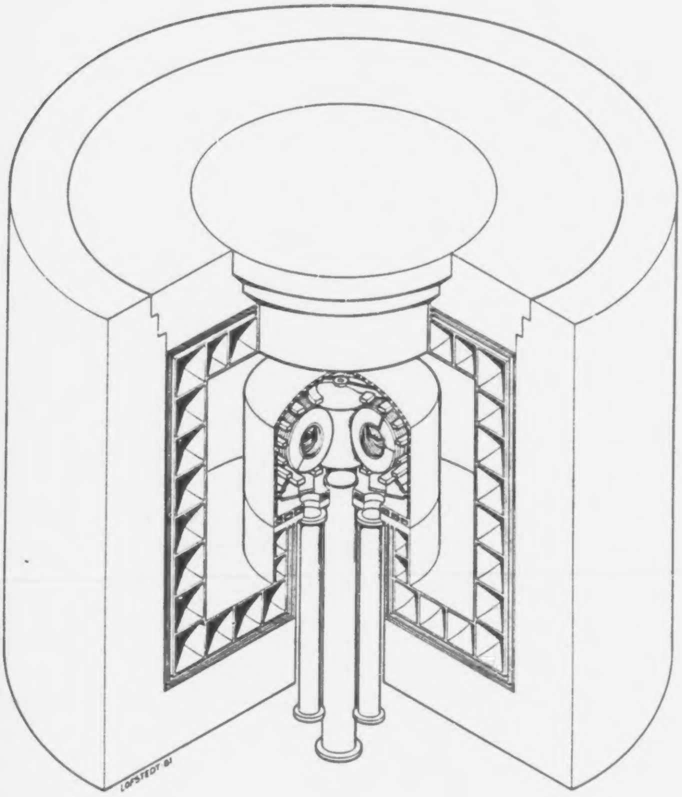
RIGGATRON^{tm} FUSION POWER CORE



SLIDE 9

What does our test device look like? I think we have said enough about comparisons and the reasons pro and con. Effectively, this is our device. The diameter is 40 to 60 centimeters. The whole device is perhaps 10 feet across. It is enclosed in a vacuum envelope and as a commercial device it would operate at 1,000 to 1,200 megawatts of fusion power. Next slide, please (slide 10).

RIGGATRON^{tm} FUSION POWER CORE IN
BLANKET AND SHIELD CELL



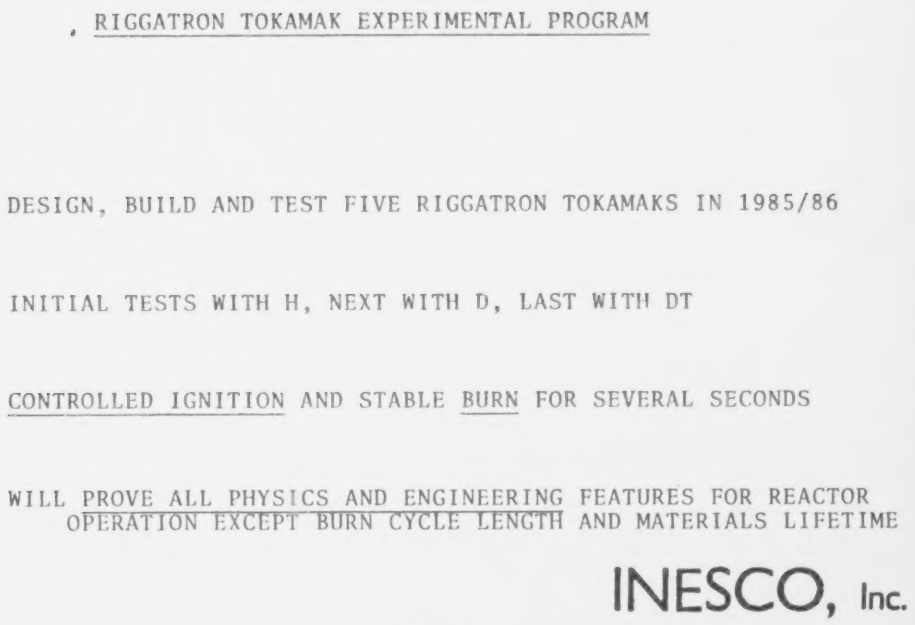
SLIDE 10

Larger powerplants could be made from a modular array of these, and here I have shown the external blanket assembly, which would represent the fixed in-place equipment, and then you would literally plug in and plug out the fusion core, much as you would with a light bulb surrounded by a lamp shade.

A modular array of these in a powerplant, of course, would have a high utilization factor simply because an extra blanket assembly would be redundant without having to duplicate the balance of plant.

Our test site that would be required to conduct this program, we feel, would need about 10 acres. We would need little tritium because the system is relatively small, and we hope to conduct tests on these five machines in an 18- to 24-month period. First, we would use normal hydrogen, deuterium, and then deuterium-tritium, much like the plan for the DOE programs.

We hope that the device will operate. Our anticipation is that it will operate for a period of several seconds. Next slide, please (slide 11).



RIGGATRON TOKAMAK EXPERIMENTAL PROGRAM

DESIGN, BUILD AND TEST FIVE RIGGATRON TOKAMAKS IN 1985/86

INITIAL TESTS WITH H, NEXT WITH D, LAST WITH DT

CONTROLLED IGNITION AND STABLE BURN FOR SEVERAL SECONDS

WILL PROVE ALL PHYSICS AND ENGINEERING FEATURES FOR REACTOR
OPERATION EXCEPT BURN CYCLE LENGTH AND MATERIALS LIFETIME

INESCO, Inc.

SLIDE 11

If we are successful, we will have proved all the physics and engineering needed for commercial units except for the length of the fuel burn cycle and the lifetime of the coil materials.

Now, we do have available data, and that data indicates that the lifetime of the coils would be of the order 1,000 hours and that the burn cycle would be of several minutes duration, and that the inter-pulse "off" time might be less than 3 seconds.

I would now like to comment very briefly about the RIGGATRON energy plant applications and just simply say that there are some spectacular numbers. Return on gross investment is of the order of 100 to 150 percent per year. These are astonishingly large. They result from two features that are inherent in the RIGGATRON.

First of all, the RIGGATRON acts much like a consumable fuel. We are burning copper, is really what it comes down to, and the balance of plant is relatively small.

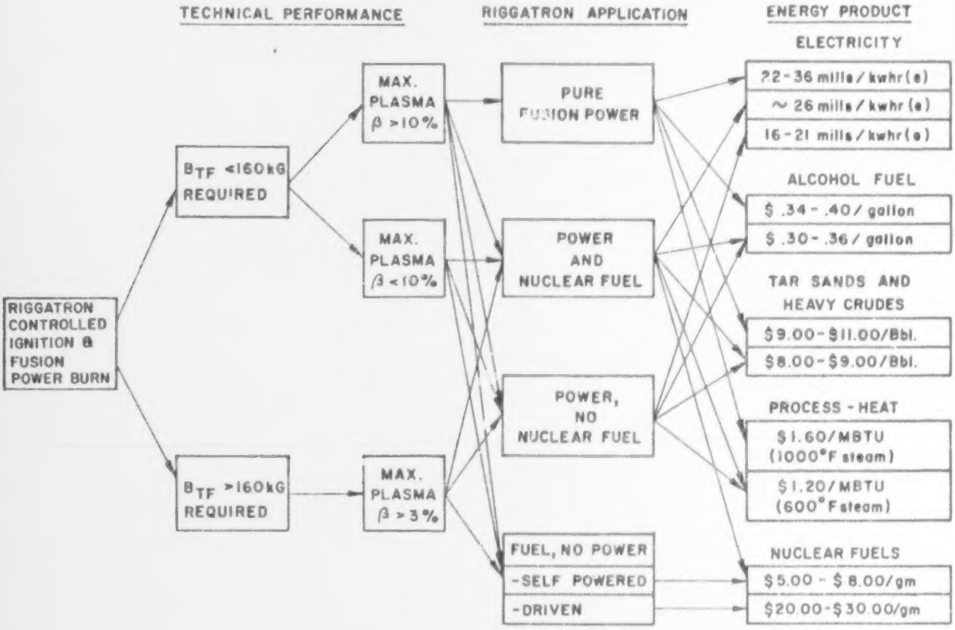
Some of the numbers indicated are fantastic—14 cents per 1,000 cubic feet of natural gas, $1.60 per million Btu of steam, 35 cents a gallon for ethanol. Now, I recognize this is a paper reactor, and it always looks better when it is on paper and then things happen when you go from concept to reality and suddenly the rules change. However, the point I want to make is not the inviolability of these numbers but the fact that they are very much below conventional prices, and that is I am off by 100, 200, 400 percent, there is room here and there is cushion here for a very economical system. I mean to say no more.

If we are successful, though, clearly this will have profound economic impact on where we are going.

The second feature which drives the economics is the fact that the capital equipment associated with the fusion energy source is small. Ninety percent of any utilization plant would be in the steam thermal conversion to electricity, and 10 percent would be in the RIGGATRON blanket.

The costs will predominately lie in proven standard technologies, and therefore, retrofitting might very well be possible.

In effect, the economics are dependent upon cheap steam and cheap neutrons. Next slide, please (slide 12).



TECHNICAL PERFORMANCE

RIGGATRON APPLICATION

ENERGY PRODUCT

RIGGATRON CONTROLLED IGNITION & FUSION POWER BURN

B_{TF} <160kG REQUIRED

B_{TF} >160kG REQUIRED

MAX. PLASMA β >10%

MAX. PLASMA β <10%

MAX. PLASMA β >3%

PURE FUSION POWER

POWER AND NUCLEAR FUEL

POWER, NO NUCLEAR FUEL

FUEL, NO POWER
-SELF POWERED
-DRIVEN

ELECTRICITY
22-36 mills/kwhr(e)
~ 26 mills/kwhr(e)
16-21 mills/kwhr(e)

ALCOHOL FUEL
$ .34-.40/gallon
$ .30-.36/gallon

TAR SANDS AND HEAVY CRUDES
$9.00-$11.00/Bbl.
$8.00-$9.00/Bbl.

PROCESS-HEAT
$1.60/MBTU (1000°F steam)
$1.20/MBTU (600°F steam)

NUCLEAR FUELS
$5.00-$8.00/gm
$20.00-$30.00/gm

RIGGATRON TOKAMAK TECHNICAL PERFORMANCE AND TYPICAL ENERGY APPLICATIONS

SLIDE 12

This is a very complicated slide which essentially says, if I can make the device ignite by all those apparently complicated paths, I can make money at it. I will leave that discussion to the testimony submitted for the record. It is attractive, and there are various physics constraints which say some routes may work and some routes may not work, but nonetheless, what it says is that if it ignites, it will make money.

Finally, Mr. Chairman, I really have to ask the rhetorical question, why am I here? I don't have any Government funding; I am not looking for any Government funding. May I have the last slide, please (slide 13)?

- ECONOMICS IS DETERMINED BY SIZE AND SIMPLICITY
- STATE-OF-THE-ART ENGINEERING
- SAME WELL KNOWN TOKAMAK PHYSICS
- BURNING PLASMA IN 5 YEARS -- NOT 25 YEARS
- EXPERIMENT IS AT COMMERCIAL SIZE
- AN ENGINEERING DEVELOPMENT PROGRAM
  NOT A SCIENCE PROGRAM

INESCO, Inc.

SLIDE 13

I would like to just simply summarize what this all means. Let me just simply read that slide: Economics is determined by size and simplicity, not exotic engineering. We are at the state of the art in engineering. We have the same well known tokamak physics as the U.S. program is using.

We hope to have a burning plasma in 5 years, not 25. The experiment is already at commercial scale, and the program is an engineering program, not a science program.

Why are we in this program? We are in it for three reasons: the sheer joy of being in it and running a good race with the U.S. program; the profits that we may obtain from the success; and, after all, the rather patriotic reason that if it is successful, it has benefits to society in general.

Mr. Chairman, 2 years ago, this committee, under Chairman McCormack's leadership, passed the Fusion Engineering Act. Despite the budget problems and the issues that I have not touched today, that act in effect said, we want fusion to happen. What we at INESCO are saying is that we believe that INESCO today may represent an excellent chance for achieving that goal in the near term.

But I also want to say, Mr. Chairman, that we need that U.S. program. Thank you very much.

Mr. YOUNG. Thank you very much, Dr. Repici. We appreciate your testimony. The testimony of all four of our witnesses this morning has been very, very important to this committee.

Without objection, I would like to insert into the record a statement from Dr. John B. Yasinsky, general manager of the advanced power systems divisions of the Westinghouse Electric Corp.; a letter to Chairman Bouquard from the University Fusion Association; a statement from the Fusion Energy Foundation; as well as the full text of the prepared statements of our panel members today.

[The prepared text of Dr. Bussard follows:]

INESCO, Inc.
6365 Lynwood Hill Road, McLean, Virginia 22101
(703) 556-8915

Testimony to the House Science and Technology Committee
Subcommittee on Energy Research and Production,
Chairman, Congresswoman Marilyn Bouquard

Statement of Dr. Robert W. Bussard, President
International Nuclear Energy Systems (INESCO), Inc.
March 24, 1982

INESCO, Inc.

Madam Chairman and Members of the Committee:

It is indeed a pleasure to appear before you today. I thank you for this opportunity. I am Dr. Robert W. Bussard, the President and Chairman of International Nuclear Energy Systems Company (INESCO), Inc. which is a privately-funded fusion development corporation. Our offices and laboratory are located in La Jolla and Del Mar, California. We currently have a staff of about 85 people. I hold a Ph.D. in plasma physics from Princeton University, and am a former Associate Director for Development and Technology of the Atomic Energy Commission's Magnetic Fusion Program.

I come here today to tell you about the scientific and technological progress which INESCO has achieved, and of the promise of our work. I hope this information will be useful to you in your deliberations, and the fact that you are familiar with our program may be beneficial to us.

In today's testimony I wish breifly to explain:

1. Who we are and what are our company's goals
2. Some basic concepts which dictate that practical fusion machines must be small
3. The RIGGATRON tokamak and our private development program to produce commercial fusion power units in 5 to 6 years

and finally,

4. The economic impact which this program will initiate.

1. INESCO and the RIGGATRON Tokamak Program

Dr. Bruno Coppi and I invented the idea of the RIGGATRON tokamak in mid-1975 as a possible means of achieving controlled fusion ignition and power burn, for a practical small scale reactor, attainable on a short time scale. We filed the initial patents and founded International Nuclear Energy Systems Company (INESCO), Inc. in late 1976 for the express purpose of carrying this idea to fruition and to commercial status. Dr. Robert L. Hirsch, then Associate Administrator for Solar, Geothermal and Advanced Energy Systems (of the USERDA) urged us to pursue the idea, and we submitted a proposal for scoping studies to the USERDA. This was funded in July 1977, and carried to conclusion in July 1978. Results of this study showed the conditions required for technical and economic feasibility of the concept.

In the Fall of 1978 we sought private funding and were supported by Litton Industries, who were interested in the possible energy plant applications of RIGGATRON units. These studies, conducted over 18 months, showed an astonishing applicability to a wide variety of energy plant types, with very large return-on-investment and large profit margins from most of the useful applications. These ranged from cheap steam for electric power production, for chemical process heat, for alcohol production, and for heavy oil stimulation and recovery, to cheap neutrons for hybrid fusion power generating for fuel production for nuclear reactors, and for nuclear waste "burning" by transmutation.

In April of 1980 our main RIGGATRON tokamak design and development program was initiated with private funds, from FDX Associates L.P. (a Delaware investment partnership), to build and test five pre-commercial prototype fusion power units by the mid-1980's. These units are planned to operate at steady burn power levels of over

200 megawatts (thermal), and will prove much of the engineering and physics necessary to allow construction, test, and manufacturing of prototype units for commercial plant applications. This privately-funded program will cost in excess of $100M over this period. Figure 1 summarizes this history of our work.

Currently we employ about 85 people full-time, with 60 full-time engineers and physicists on our staff. Our main offices are in La Jolla, California, and our materials development laboratory is in Del Mar, California. We maintain a corporate liaison office in McLean, Virginia. Work conducted to date in our main effort has led to detailed design for our first fusion test units, and to the successful development of all basic materials needed to assure the engineering integrity of these units. Our materials development has been conducted privately in concert with Brush-Wellman, Cabot-Berylco, and the International Copper Research Association. Over the past year we have improved the strength and conductivity of commercially available alloys to the extent that these materials now significantly exceed the requirements of our most under-designed fusion machines. We have also defined our test power supply and test facility needs, and are engaged in final site selection for our five machine demonstration testing. Figure 2 summarizes our current status.

It is important to note that the RIGGATRON tokamak design is based solidly on all the physics knowledge derived from all of the world's tokamak research conducted since its invention (in late 1960's) by Soviet Academician Lev Artsimovich. The high field tokamak research programs at MIT (the Alcator program) and Frascati,

FIGURE 1

INESCO/RIGGATRON^{TM} TOKAMAK FUSION PROGRAM BACKGROUND

- RIGGATRON TOKAMAK CONCEPT INVENTED IN MID-76 (BUSSARD/COPPI)
- INESCO FORMED IN LATE 76 TO DEVELOP CONCEPT TO COMMERCIAL STATUS
- INITIAL SCOPING/DESIGN STUDY (ERDA/DoE CONTRACT, JULY 77-JULY 78) DEFINED ENGINEERING CONDITIONS FOR TECHNICAL AND ECONOMIC FEASIBILITY
- ENERGY PLANT SYSTEMS STUDIES (LITTON SUPPORT, SEPT 78-MARCH 80) SHOWED RANGE OF APPLICATIONS, PLANT ECONOMICS, PRODUCT COSTS
- RIGGATRON DEVELOPMENT AND DEMONSTRATION PROGRAM INITIATED (APR 80 - PRESENT, BY FDX ASSOC.) TO BUILD AND TEST FIVE PRE-COMMERCIAL PROTOTYPE FUSION UNITS AT SEVERAL HUNDRED MEGAWATTS FUSION POWER LEVEL BY MID-1980'S.

FIGURE 2

INESCO/RIGGATRON^{TM} PROGRAM CURRENT STATUS

- MAIN OFFICE IN LA JOLLA, CALIFORNIA; CORPORATE OFFICE IN McLEAN, VA.
- MATERIALS DEVELOPMENT LABORATORY IN DEL MAR, CALIF.
- 85 FULL-TIME STAFF: 60 ENGINEERS AND PHYSICISTS
- PRELIMINARY DESIGNS COMPLETED OF FULL-SCALE RIGGATRON TEST UNITS
- MATERIALS DEVELOPED TO EXCEED ALL MACHINE OPERATIONAL REQUIREMENTS
- MAIN TEST/DEVELOPMENT SITE SELECTION IN PROCESS

INESCO, Inc.

Italy (the FT tokamak) have been of particular value in this regard. Our program utilizes no new engineering technologies and no new confinement physics; we have simply taken an engineering approach of high power density design (characteristic of the aerospace industry, rocket and jet engines) to reduce tokamaks by a factor of 1000 to sizes suitable for practical development and use.

The question remains if current well-proven tokamak confinement laws will still hold at the conditions needed for power reactor operation, which our RIGGATRON machines hope to achieve. This is the only unknown issue in our program. It is the same issue which confronts all the world's fusion programs; will current proven confinement laws still hold at higher levels? We have reason to believe this is likely when we note that the parameters of heating and confinement in tokamaks have been increased by a factor of over 10,000 since the tokamak concept was first conceived. The RIGGATRON unit must go only another factor of about 2 to be successful. We intend to prove this by our full scale RIGGATRON machine experiments. If some wholly unexpected new phenomenon causes our tokamak to fail, then it is likely that all tokamaks will fail. Generally, however, plasma physicists throughout the world believe that the tokamak scaling laws will extrapolate successfully.

In Figure 3 our commercial development plans are outlined. We intend to commercialize as rapidly as possible after success of our five machine tests in 1985-86. To do so we will be developing a manufacturing capability as we progress, will design prototype commercial units in 1986-87, and hope to work with major industrial

FIGURE 3

RIGGATRON^{TM} FUSION UNIT COMMERCIAL DEVELOPMENT PLANS

- CONDUCT DEVELOPMENT PROGRAM TO PROVE ALL PHYSICS AND ENGINEERING FOR COMMERCIAL USE: 5 MACHINES AT 200 MEGAWATTS (1985-86)
- DEVELOP MANUFACTURING CAPABILITY (1984-86)
- DESIGN COMMERCIAL UNIT
- WORK WITH INDUSTRIAL ORGANIZATIONS IN ENERGY PLANT DESIGN (1983-86)
- FIRST COMMERCIAL PROTOTYPE DEMONSTRATION PLANTS (1987-89)
- RIGGATRON PLANT DEPLOYMENT AT MAXIMUM RATE INTO WORLD ENERGY MARKETS (1990-   )

INESCO, Inc.

organizations prior to 1986 to define RIGGATRON-using energy plant designs and develop energy plant sub-systems to acceptable status for commercial use in 1987-89. After the first few demonstration plants are running in 1989-90, we intend to deploy into world commercial energy plant markets at the maximum possible rate.

2. Basic Concepts and the Need for Small Machines

You will recall from various DoE technical presentations that fusion is the process whereby we "fuse" or bring together two lighter elements to form a heavier nucleus accompanied by the release of energy. The specific process of interest is fusion of the two heavy isotopes of hydrogen, deuterium and tritium (D and T), to form helium and a neutron. The majority of the reaction energy is carried away by the neutron.

To initiate a fusion reaction in a controlled manner, a gaseous mixture of deuterium and tritium is ionized to form a plasma, i.e., sufficient external energy is added to the D and T gas micture such that the electrons are stripped from the D and T ions and form a "gas" of charged particles known as a "plasma". We then have a highly energized gas or plasma of dissociated ions and electrons. Although the bulk plasma has no net electric charge, the dissociated ions and electrons have a charge and hence can be confined or held together on magnetic field lines. If these field lines are generated by magnet coils of the proper shape to form a "magnetic bottle", we will be able to hold the mass of plasma away from the walls of this "bottle".

To achieve fusion enough energy must be invested into the plasma so that the D and T ions become so energetic that they have sufficient energy to overcome the electrical forces of repulsion which exist between ions of similar charge. When sufficient energy is introduced, this coulomb repulsion is overcome, so that the D and T ions can actually collide and "stick" together, i.e., to fuse.

This energy investment expressed in scientific terms means that the plasma must have a minimum temperature T. In addition to this threshold temperature there is an additional threshold condition known as the Lawson criterion. This criterion requires that the plasma have a certain density and a certain interaction time or confinement time whose product defines the fusion reaction threshold. To the extent that the density (n) is large, the interaction or confinement time (τ) can be small, or, to the extent that the interaction time is large, the density can be small. The criterion is conceptually logical: It says that a sufficient number of particles must be present for long enough in an interacting or confinement region for the fusion process to occur. This is summzrized in Figure 4.

If we now look at the magnetic bottle which holds the plasma together to form a confinement or interaction region, we see that the physical size of that bottle is determined by the strength of the confining magnetic field (B) which must overcome or control the kinetic or heat energy invested in the plasma ion particles. Now, the energy contained in a unit volume of the plasma is determined by the number of particles in that unit volume which is just the

FIGURE 4

BASIC FUSION PHYSICS CONSTRAINTS

DT FUSION CAN BE ACHIEVED ONLY WHEN THE DT PLASMA IS CONFINED LONG ENOUGH AT HIGH ENOUGH DENSITY AND TEMPERATURE TO YIELD MORE ENERGY OUT THAN IN

THE PRODUCT OF CONFINEMENT TIME (τ) AND DENSITY (n) MUST BE LARGER THAN A VALUE SET BY PHYSICS LIMITS TO YIELD USEFUL POWER. THIS IS CALLED THE "LAWSON CRITERION" (K_1)

$$n\tau > K_1$$

plasma density. This means that if we wish the plasma to be more dense then we must increase the strength of the magnetic field.

However, if we are limited by the strength of the magnetic field which we can produce, then that magnetic field limitation defines the maximum plasma density at which we can operate. This maximum attainable density then defines the needed confinement time that must be achieved if the Lawson criterion is to be satisfied.

This confinement time, the time an ion spends in the interaction region, can be made larger simply by making the interactive region larger.

Where does this all lead us? As shown in Figure 5, it says quite simply that if you choose to use superconducting magnets, which have limited field strength capabilities to confine the plasma, then the plasma region must be very large. This is what the mainline fusion program has done. There is a minimum size for a superconducting machine and it is very large and therefore very expensive to build, and very expensive and time-consuming to develop.

The alternative is to use copper magnets whose field strengths can be made very large, and hence the plasma made very small but dense. Consequently, with a high strength small magnet the capital expense is made small, and the development time and costs are made small. This is what our RIGGATRON fusion program is all about.

In summary, both we and the Department of Energy recognize that the tokamak is the only known and proven successful scheme for fusion plasma confinement. Although there may be valid reasons for

FIGURE 5

BASIC FUSION PHYSICS CONSTRAINTS

WITH SUPERCONDUCTING MAGNETS THE ATTAINABLE FIELDS (B) ARE TOO SMALL TO ALLOW SMALL MACHINES. THUS,

SUPERCONDUCTING MAGNET MACHINES MUST BE LARGE

LARGE SIZE MEANS LARGE COSTS AND LONG DEVELOPMENT TIMES THIS IS THE SO-CALLED "MAINLINE" APPROACH

WITH COPPER MAGNETS, HIGH FIELDS CAN BE REACHED WHICH ALLOW SMALL SIZE, THUS

COPPER MAGNET MACHINES CAN BE SMALL

THIS IS THE INESCO/RIGGATRON TOKAMAK APPROACH developing the large low density devices, we feel that small size is required for low-cost, short development time, and practical plant applications.

3. The RIGGATRON Tokamak Development Program

The fundamental engineering innovation which we have introduced in fusion reactor design was nothing more or less than the use of water-cooled copper alloy conductors for high magnetic fields in a tokamak of very small size.

Our technical approach as shown in Figure 6 is to design machines to their engineering limits, and then experimentally test to those limits, to determine with precision the actual regime for operational success. This is possible only because the machines, themselves, are relatively inexpensive and easily replicated.* With this approach it is possible to conduct our development program in the classically successful mode of learning-by-doing, by successive testing of many machines.

Figure 7 illustrates the features of RIGGATRON small size in comparison with the "mainline" concepts for superconducting magnet machines to utilize shields and lithium blankets (required by breeding T) inside the main toroidal magnets. This limits useful field strength and requires large and complex machines. In contrast, the copper magnets of the RIGGATRON are placed directly around the fusion plamsa region, allowing the required lithium blanket to be placed external to the fusion unit, and physically separate from it.

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*Less than 10% of our total program cost is due to the cost of the five machines planned for demonstration testing.

FIGURE 6

INESCO TECHNICAL APPROACH

DEVELOP VERY SMALL TOKAMAK FUSION MACHINES

USE WATER-COOLED, HIGH STRENGTH, COPPER ALLOY MAGNETS

USE PLASMA OHMIC HEATING AS PRINCIPAL IGNITION MEANS

DESIGN DOMINATED BY ENGINEERING LIMITS

DRIVE THESE UNITS VERY HARD, WITH LIMITED LIFE, BUT AT LOW UNIT COST/POWER PRODUCED

PERFORMANCE DETERMINED BY SUCCESSIVE TESTING OF MULTIPLE INEXPENSIVE MACHINES

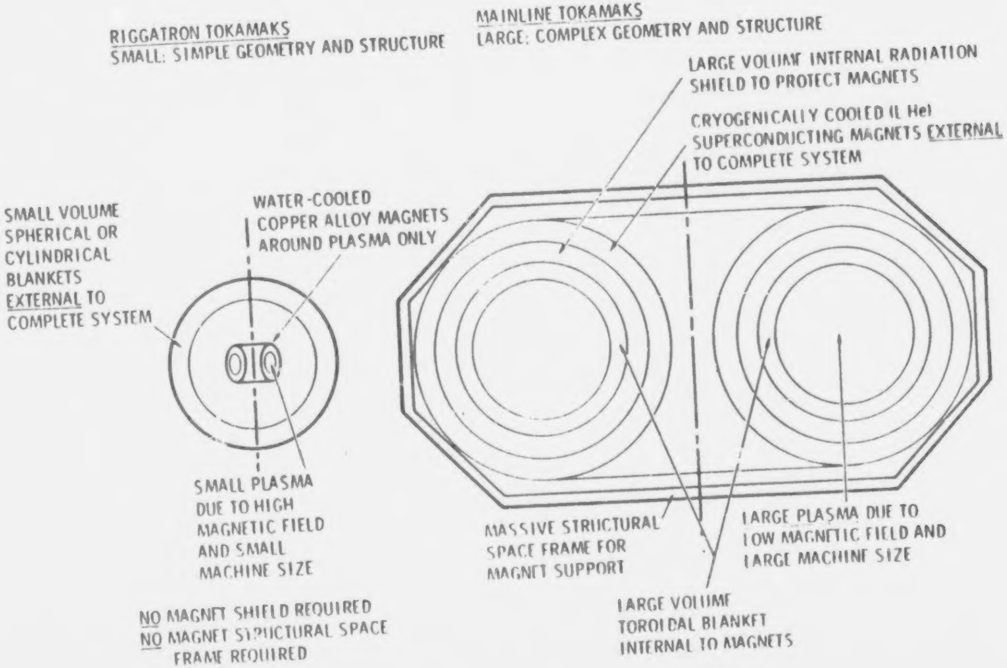
CONSTRUCT POWER PLANTS FROM MODULAR ARRAYS OF FPC UNITS

DISPOSE/RECYCLE USED UNITS

LOW UNIT COST YIELDS ATTRACTIVE ECONOMICS FOR CENTRAL STATION POWER PLANTS

FIGURE 7

COMPARISON OF GEOMETRIC AND STRUCTURAL CHARACTERISTICS OF TOKAMAK FUSION OPTIONS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LARGE VOLUME TOROIDAL BLANKET INTERNAL TO MAGNETS

The blanket remains - like a lampshade - while the internal fusion "light bulb" is removed and replaced when it wears out.

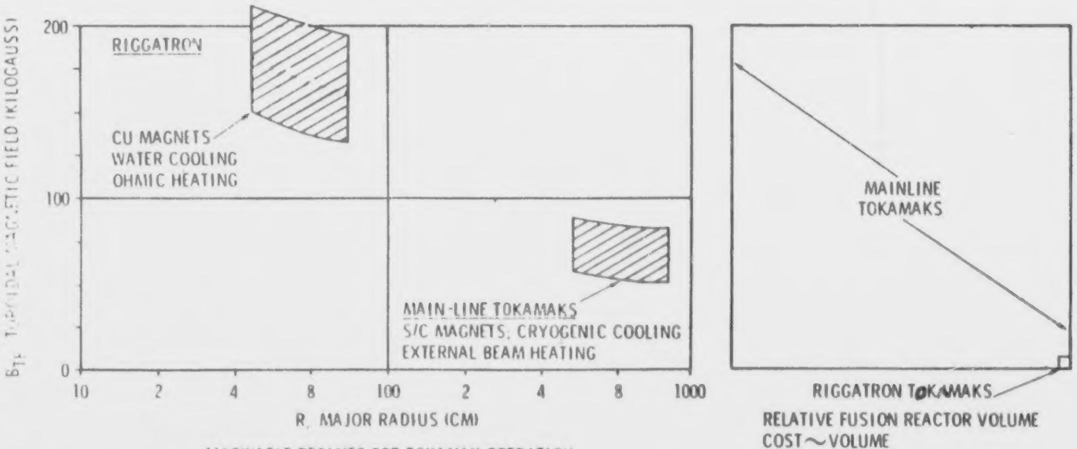
As Figure 8 indicates the "design space" for RIGGATRON machines is at a higher field but at a tenth smaller size than is possible for superconducting "mainline" tokamaks. Note that the RIGGATRON is only a few feet in radius. This ten-fold reduction in size is a thousand-fold reduction in plasma volume. Since machine cost varies roughly as the volume, and since copper alloys cost less than superconductors, RIGGATRON machines inherently will cost 1000 to 4000 times less than their larger superconducting tokamak cousins.

What does our test unit look like? Figure 9 shows an artists sketch of a canned "light bulb-like" RIGGATRON tokamak. Here we see that the entire fusion unit is enclosed in a vacuum envelope, much as a filiment in a conventional light bulb. Such a unit assembly will be placed inside a shielded room whose walls are lithium tanks to serve as the T breeding blanket, as indicated in Figure 10. Each such assembly (blanket plus RIGGATRON unit) would be capable of operating at 1000-1200 megawatts of fusion-generated power. Heat from the blanket and fusion unit would then be used to generate 1000°F steam which can be converted to 250-350 megawatts of electric power output. The steam output can, of course, be used for other purposes (e.g., as process heat at 1000°F).

Larger power plants can be made from a modular array of such systems. In any RIGGATRON plant, a high utilization factor can be obtained by providing one or two "extra" blanket/RIGGATRON units in the plant. When one unit is shut down for fusion core unit replacement, the "spare" unit is turned on so that there is no plant down

FIGURE 8

TECH APPROACHES TO TOKAMAK REACTORS
RIGGATRON & MAINLINE TOKAMAKS



ALLOWABLE REGIMES FOR TOKAMAK OPERATION

COMPARISON OF TECHNOLOGICAL FEATURES OF TOKAMAK FUSION OPTIONS

FIGURE 9

RIGGATRON^{tm} FUSION POWER CORE

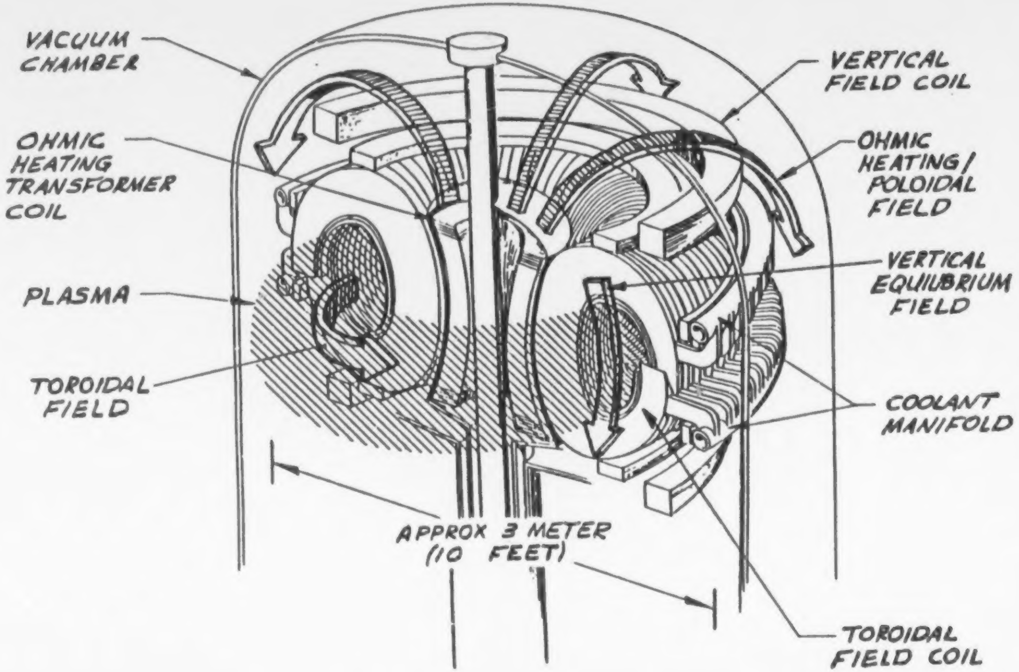
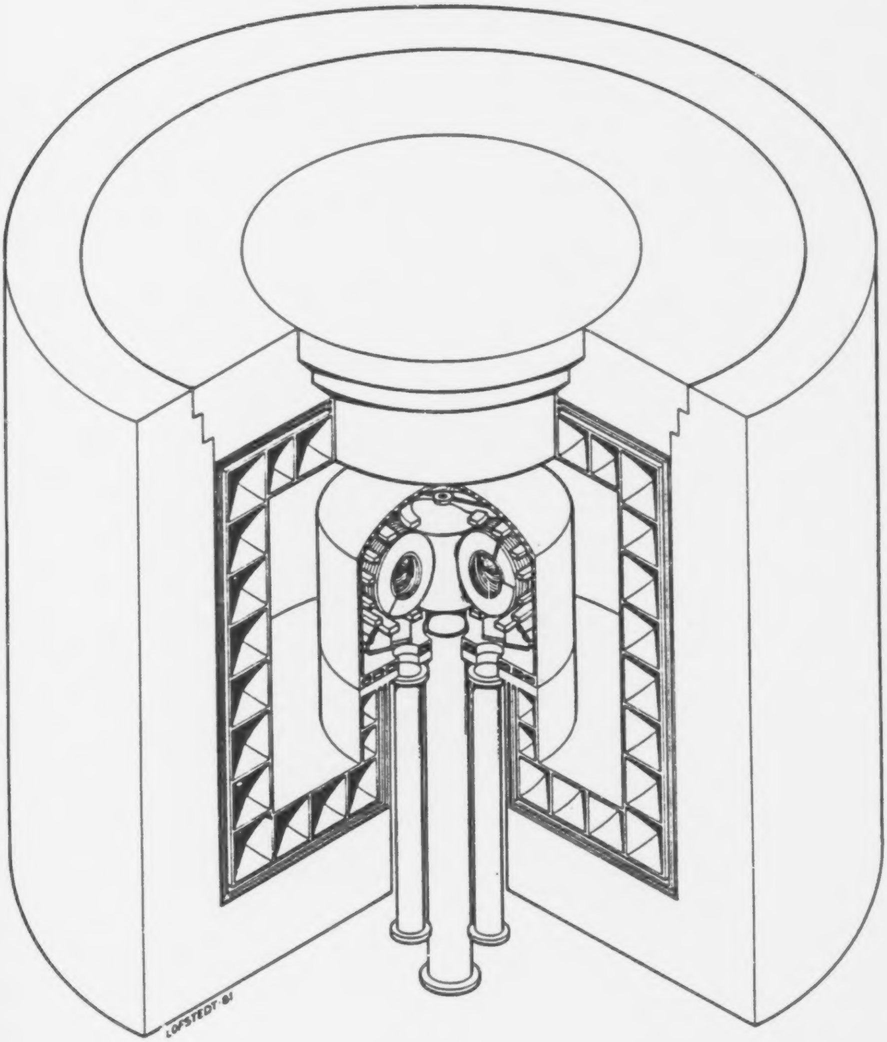


FIGURE 10

RIGGATRON^{tm} FUSION POWER CORE IN BLANKET AND SHIELD CELL



time due to unit failure or replacement. Replacement time can be less than 8 hours, because the unit is a canned assembly and is easily disconnected, removed, and replaced. This "plug in" quick-disconnect approach was pioneered and proven in the national nuclear rocket (Rova) program over 20 years ago.

The test site required for our five demonstration test machines requires only about 10 acres of land for site safety and compliance with all regulatory and hazard requirements. Very little tritium is on-site at any one time because the system is so small. We plan to carry out tests over a period of 18-24 months with parallel test cells. Initial tests will ve made with normal hydrogen, later with deuterium alone, and finally - for ignition/burn experiment - with D&T mixtures. These final tests will operate at full, steady, controlled burn for periods of several seconds; long compared to the energy confinement time of the plasma in the machines. Such tests will prove all the physics and engineering features needed for prototype commercial units except the maximum attainable length of the fuel burn cycle and the radiation damage lifetime of the coil materials.

Available data on copper alloys suggests that the lifetime may be approximately 1000 hours at operating conditions appropriate to commercial plant use. Our analysis also suggests that burn cycle length may be as large as several minutes before machine pump down is required. Inter-pulse "off" time could be less than three seconds, due to the small volume requiring pumping. This test program is summarized briefly in Figure 11.

FIGURE 11

RIGGATRON TOKAMAK EXPERIMENTAL PROGRAM

DESIGN, BUILD AND TEST FIVE RIGGATRON TOKAMAKS IN 1985/86

INITIAL TESTS WITH H, NEXT WITH D, LAST WITH DT

CONTROLLED IGNITION AND STABLE BURN FOR SEVERAL SECONDS

WILL PROVE ALL PHYSICS AND ENGINEERING FEATURES FOR REACTOR OPERATION EXCEPT BURN CYCLE LENGTH AND MATERIALS LIFETIME

4. RIGGATRON Unit Energy Plant Applications and Economic Prospects

Over the past 3½ years we have made studies of the potential application of RIGGATRON tokamaks to a wide variety of energy plant and process steam uses. Results of these studies show that the return-on-gross-assets (ROGA) is 100%-150% per year for the range of plants which can benefit from RIGGATRON fusion. These astonishingly large values (by comparison with conventional energy plant economics) are a natural result of two features inherent to the RIGGATRON tokamak concept and to the means for its plant employment.

First and foremost of these is that the RIGGATRON device acts, economically, like a consumable fuel in an energy plant. It is not a long-lived, fixed depreciable asset but is used up over a period of about 1000 hours*. Its cost thus appears as an operating cost (analogous to fuel cost in oil-burning plants) rather than as a capital cost. Its attractiveness stems from the fact that the unit energy cost of RIGGATRON units or "fuel" calculate to be only about $.50/bbl. of oil equivalent, or $0.14 MCF for natural gas. Compare these to today's market prices at approximately $30/bbl. of oil and $5/MCF gas. I grant you that the RIGGATRON, today, is only a "paper reactor". However, even with the inevitable cost escallations which invariably occur as concept becomes reality, the cost advantage "cushion" is still extraordinarily attractive.

If successful, the deployment of RIGGATRON-driven plants in the early 1990's would have a significant effect on world market prices of oil and natural gas and, to a lesser degree, coal.

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*1000 hours in pure fusion plants; 5000+ hours in "hybrid" fusion-driven plants.

The second feature of RIGGATRON fusion unit applications to energy plants which augers for dramatically lower costs, or for large profit margins, is that the capital equipment associated with the fusion energy source portion of the plant is only a small fraction of the total plant cost. Our studies show that the capital cost of a RIGGATRON fusion-electric power plant is split approximately 90% to conventional equipment (for thermal conversion to electricity) and to balance of plant, and only 10% (or less) to the relatively small scale RIGGATRON-unit-related equipment. The RIGGATRON steam/electric plant costs will be predominantly in proven, standard plant equipment. This means that RIGGATRON units can be retro-fitted to many current oil and gas burning energy plants, at acceptably low costs for such conversion. Inexpensive retro-fitting for RIGGATRON fusion could be a cheap and fast way to remove oil and gas from our country's power plants. This does not mean that new plants will not be needed; quite the contrary. RIGGATRON retro-fitting will lead to lower energy costs but at the price of a 20% reduction in plant output. This, coupled with the continued growth which our society requires, leads to a need for new plant construction. The total capital cost of new plants constructed for RIGGATRON use will be significantly less than for conventional nuclear reactor plants, and will be about the same as current fossil-fuel-fired plants, but the on-going "fuel" costs will be virtually zero.

We estimate that the cost of steam from RIGGATRON steam plants to be about $1.60/MBtu (1980 $) at 1000°F, or $1.20/MBtu at 600°F, considerably less than the current cost of oil or of natural gas at the wellhead. Steam at these prices can displace most other sources of steam for process heat, in a wide variety of industrial applications. Since over 90% of energy in the U.S. is used for thermal non-electric applications, the RIGGATRON can have a profound impact on these industrial sectors as well as on the electric power utility business.

As one example of this impact we have considered the production of ethyl alcohol. Ethyl alcohol, or ethanol, is an excellent fuel capable of powering automobiles and jet aircraft, and for other heating purposes. Today it is too expensive to compete with gasoline except in a price-regulated economy, such as that in Brazil where one million cars currently are running on ethanol. Ethanol is made by the fermentation and subsequent distillation of biomass feedstocks, at medium temperatures (up to 500°F). Alcohol for beverages is made from corn, potatoes, sugar beets, rye, and sugar cane, among other feedstocks. The sugar can process involves crushing and squeezing the cane to extract the juice, and use of the crushed pith and husk to burn as fuel to heat the fermentation and distillation process for conversion of the juice to ethanol.

With an external energy source such as fusion, via the RIGGATRON unit, the pith also may be fermented, the husk removed more carefully for wood byproduct use, and the resultant cost of anhydrous fuel-grade ethanol is found to be about $0.35/gallon (current ethanol costs for conventional plants are over $1.60/gallon). At this cost ethanol can compete well in the market place with gasoline for automotive use. One RIGGATRON-unit-driven plant can produce about 5000 tons/day of ethanol from a high yield cane field about 18 miles square. The cost of such a plant is estimated to be $400-500M (1980 $).

Two hundred such plants could fuel all the cars in the United States, and we could stop using gasoline, to the benefit of our air pollution problems as well as to our freedom from fossil fuel dependence. Sugar cane is a solar-energy-grown crop, completely renewable, and the fusion fuel which drives the plant is inexhaustible. Some years ago the American Petroleum Institute (API) commissioned a study which showed that the energy required to produce alcohol exceeded the energy available from the alcohol thus produced, and concluded that alcohol production was not a fruitful way to attempt to solve the nation's oil problem. This conclusion is valid only for alcohol plants which run on conventional fuels; it is not true for RIGGATRON fusion unit plants in which the energy required is produced at extremely low cost. The point here is that the use of RIGGATRON fusion-produced steam yields low-cost alcohol both because the required process heat (steam) is very cheap and because the operating characteristics of the plant are changed.

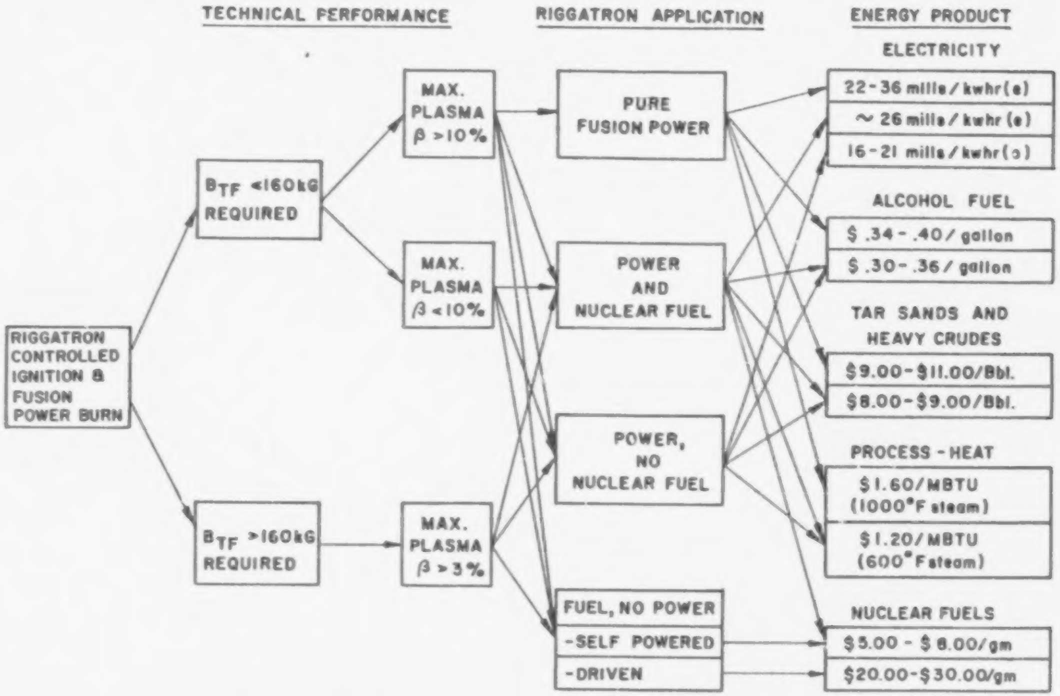
Other plant applications which appear of global significance are the production of agricultural water from sea water at $1.00/thousand gallons at the bottom end of a steam-electric plant with electricity produced at ca. 30 mills/kw_ehr at the busbar, steam stimulation of "heavy" oil wells and oil extraction from in-situ tar sands with savings of $3-6/bbl produced, generation of safe reactor-grade nuclear fuel at 1/3 to 1/2 of current world market prices, and the effective "burn up" of radioactive wastes from the world's nuclear reactors, with subsequent storage times reduced to less than one hundred years, rather than tens of thousands of years as at present.

Figure 12 schematically shows our total program from demonstration-experiment to commercial plant uses, by all of the possible technical routes. It is important to note that nearly all of the wide array of commercial plant applications can be achived no matter what levels of plasma performance are found to work successfully, provided only that controlled ignition and burn is achieved in the RIGGATRON demonstration experiments planned in our program.

All of these potential commercial applications, and others not mentioned here, come about because the RIGGATRON unit is small and cheap, and inherently can operate in an inexpensive manner in nearly all plant applications. All can be achieved if the RIGGATRON device successfully reaches ignition and controlled burn. RIGGATRON fusion energy can renew the United States' great strength, and can re-vitalize the world, giving mankind a new breadth of life and a new vision for our future.

Finally, Madam Chairman, you and your committee may well ask, "Why is Dr. Bussard telling us all this? We do not have government funding, and we are not seeking government funding. However, I believe it is important that you should know what we are doing and what we plan to do. Such knowledge should be helpful to you, as you plan the directions of the country's federally-financed energy developments. And it should be beneficial to us, as you act on that

FIGURE 12



RIGGATRON TOKAMAK TECHNICAL PERFORMANCE AND TYPICAL ENERGY APPLICATIONS knowledge, to help prepare the way for the most rapid and efficient industrial and commercial acceptance of our machines, as these reach commercial product status in the late 1980's.

If our machines work, we will have successfully controlled the fusion thermonuclear reaction at extremely high power levels, of hundreds of megawatts, in a small device which is easy to build and deploy commercially. In the economic sphere, this event will have a more profound and pervasive impact than the first successful uncontrolled thermonuclear reaction had some 30 years ago in another sphere. This is not a 30-year promise. This event will happen within 5-6 years, and you should know of our program.

Madam Chairman, we are here today to represent our corporation's best interests. We are in this program for three reasons important to us. One is just the sheer joy of winning, with a better technological idea than all the others. Another is the desire to make large profits from our success, without any federal subsidy, in a realistic time frame. This, we believe, is the essence of private enterprise in a capitalistic society. And finally, we believe that this machine, properly employed, can forever change the world for the better and alter the balance of industrial and economic power on the planet. If we are correct, and the RIGGATRON systems perform as analyzed, the very nature of the industrialized world will be shifted dramatically from fossil fuels to fusion, not because the RIGGATRON device is a clever engineering achievement, but because it offers an economic miracle, a return to cheap energy - forever - in a framework which fits nearly all current industrial infrastructures. There is no OPEC to control the fusion fuels in the oceans, lakes, and rivers of the world.

If this works it will work within the next 5 to 6 years, and the national policy issues which this will generate must be discussed in this time frame if we are to exploit it properly. We do not have the liesure which a 30-year scientific program implies.

Madam Chairman, two years ago, this committee and this Congress, under Chairman McCormack's leadership, passed the Fusion Engineering Act of 1980. The objective of the McCormack Fusion Act was to "make fusion happen". We believe that INESCO, today, represents the best chance for achieving that goal. If INESCO is successful as we anticipate, then private enterprise, building upon the basic research investment made by the government, will have again demonstrated its ability to efficiently solve technology problems and make a profit.

Thank you.

Mr. YOUNG. At this time I would like to recognize Mr. Lowery, who would, I am sure, want to welcome some of the people from southern California who were such great hosts to us in January. Mr. Lowery?

Mr. LOWERY. Thank you, Mr. Chairman.

I hope the panelists will excuse my bouncing in and out of the committee meeting and try to understand that I have three committee meetings going simultaneously right now, so please understand.

I do want to welcome all of the panelists, this panel and the following panel. I am looking forward to all the testimony and enjoyed the testimony that we just heard.

I just made a couple of notes during Tihiro's testimony, on how pessimists talk about fusion being 50 to 70 years out. I am convinced that if we make a commitment as a nation, it will certainly be here within 25 years. I see such parallels to where we were in the fifties when men and women of vision would suggest that we could put a man on the Moon within 20 years, and they were probably looked upon as if they were smoking some kind of exotic rope.

But it was possible. We did make that commitment. I think of where we are today in the depletion of the traditional fuels we have used, the fossil fuels, and where we are going to be as we move into the next century, which is really just around the corner.

I have concerns about air quality. We are just now beginning to get into such subjects as acid rain. Look at air pollution and what we are doing to foul the air in our urban areas from traditional fuel sources of coal and oil.

Admittedly, I am not a scientist and I don't have the technical background in engineering or in scientific efforts, but I think I have a general understanding of the concepts and where America needs to be.

I guess I view the fusion program as possibly being, just possibly being, the most important body of research that we are doing in the country today in terms of maintaining in the next century the quality of life that we as Americans now know and the high standard of living we have had.

I guess there are few areas where we can have such a symbiotic relationship between environmental and economic concerns, but it is all brought together in fusion, not to mention a sense of energy self-sufficiency in the next century unlike we are able to enjoy currently, and all of the foreign policy applications that that has.

I have analogized the space program. It just strikes me where we are today is a matter of making the commitment, of making it happen, and doing it with various technologies, some of which will work, some of which will not, but doing it in a concurrent manner rather than stretching it out. Because if we had taken that same approach through NASA in the sixties, we would not have put a man on the Moon in the early seventies; we would still be fooling around and thinking about it without having various courses that we are taking to arrive at the goal.

We do not know which path is going to pay off for us, but we need to fund them all. That, Mr. Chairman, is kind of an overview. It just gives you one little old Congressman's overview of where I think we are and where I think we could go.

Mr. YOUNG. Thank you very much, Mr. Lowery.

We will now proceed with questions of the panel. The first question I would like to ask Mr. Matson. How can the producer and user communities of future fusion devices play a role in the program at this early stage of development?

Mr. MATSON. Mr. Chairman, I might give you one perspective from the utility point of view. We at Public Service Electric & Gas in New Jersey have been involved in the fusion program through work at and with Princeton University since about 1957. We have a research and development subsidiary, and we have taken a rather strong role, you might say, for a utility in fusion development. We have actively sought out funded contracts from bodies such as the DOE and Electric Power Research Institute. We have been actively trying to inject into those studies and ongoing programs the utility or end user perspective of what is needed for a program to succeed in that it be used or usable by a utility, a prospective end user.

In that respect, I think it is important that people such as utilities, the end user, are involved to look at what the prospective siting and safety issues are. I think we have learned a great deal by our very direct involvement in the fission program, and I think we are able to bring that over into the fusion program and, hopefully, add that perspective.

Mr. YOUNG. Thank you very much.

The figures that were cited by Dr. Repici are pretty interesting when we take a look at where we are. We have two homes, one in St. Louis with natural gas and one up here with electric, and those cost estimates for fusion power look pretty good.

Dr. Ohkawa, I understand that General Atomic is developing, along with Phillips Petroleum, the OHTE device, which has been described to me as a combination of reversed-field-pinch, and a stellarator device. Is this a correct description, and could you please describe this device in some detail to the subcommittee?

Dr. OHKAWA. The OHTE concept is a new type of magnetic bottle, toroidal variety but high beta. It uses, as you said, the pinch-like plasma. Also, it uses helical winding, which is somewhat like stellarators but with confinement physics. It is a new variety of magnetic bottle.

We have built an experimental device, and we have a 3-year research agreement with Phillips Petroleum. We have gone through the first year of experimentation. So far, the results obtained look very encouraging.

Mr. YOUNG. How much private capital has gone into the development of the OHTE device? How much more may be required to assess whether or not the device will work?

Dr. OHKAWA. The first phase is on the order of $20 million investment, $10 million from General Atomic and $10 million from Phillips Petroleum, to assess the physics of this new device in 3 years. With success, we are planning to have a second phase which might involve a much larger investment.

Mr. YOUNG. Does General Atomic's private investment in the OHTE mean that General Atomic does not believe that the tokamak and mirror devices being developed by DOE will evolve into viable commercial reactors?

Dr. OHKAWA. No, this is not mutually exclusive. It is the research and development portfolio, just like a financial investment portfolio. You have a spectrum of investments in several areas. With the high-risk, high-reward situation, you invest a smaller sum compared to the low-risk approach.

So we consider we are doing a balanced R&D portfolio.

Mr. YOUNG. Thank you very much.

Dr. Repici, in contrast to the large devices being developed by DOE which require auxiliary heating of some sort, the RIGGATRON is expected to achieve ignition by ohmic heating alone. Can you explain in greater detail why you think you can generate high enough temperatures in this manner?

Dr. REPICI. Mr. Chairman, the temperatures that you can generate are a function of the physics and the power supply and the engineering.

The contribution that Dr. Coppi made to the high-density concept, which evolved into the RIGGATRON concept, was that he recognized, that when one gets near ignition, by ohmic heating you generate significant alpha particles. He coined the phrase—I believe he is responsible for the phrase, at least—of alpha particle "bootstrapping." This is the effect by which the deposition of energy into the plasma by the alpha particles which you produce, further raises the temperature of the plasma and lets you go the extra distance into a fully ignited region.

The other method of heating besides ohmic heating—it is a small device, so it is not amenable to neutral beam heating, is RF heating which is an appropriate mechanism for heating a small device. So we and our technical people feel very confident that the combination of ohmic heating and, if necessary, RF heating will put us into the ignition region.

Mr. YOUNG. To Dr. Ohkawa and to Dr. Repici, this will be my final question. Are there similarities between your in-house corporate programs in fusion and the DOE program which can help advance the generic fusion effort?

Dr. Ohkawa, would you want to take that first?

Dr. OHKAWA. I have to correct the impression on the OHTE. This is not entirely private. We do use some Government equipment. In that sense, it is partly Government, in a small part.

Yes, I admire the entrepreneurship of INESCO, that they are trying to do the high-risk development with private funds. The whole spectrum of the approach should be taken. When it comes to Government versus private, the long-range program should be, of course, financed by Government. But if, as the INESCO approach indicates, there is a very high risk and high reward in the short term, there is a possibility the private funds might support it.

Mr. YOUNG. Dr. Repici?

Dr. REPICI. I have to point out the similarities which both Tihiro and I have are that both of our devices are relatively small, and I think that fact permits a nearer term device; also, if it is going to be nearer term, it must be something from which we can achieve some economic gain, some potential.

With respect to your question, Mr. Chairman, about the relationship between private industry and the DOE, we are not a DOE contractor. In fact, our backers are concerned that we should have any contract whatsoever so as not to endanger our patent position. So we have no Government support whatever.

Now, the people that we have, in all candor, come from the U.S. program, talk to their colleagues, and there is a certain low level cooperation. Contrary to the comments made yesterday, there is very little that the Department is giving to us, even though they would like to give us more. When the AEC was set up there was never any thought given to the possibility of private industry doing fusion on its own. Despite the best efforts of the OER management, we are really not able to have access, free access to computer time, to machines, to the diagnostics, simply because we are not a DOE contractor. If I had a $10,000 contract with the DOE, we could cure it, but I cannot. That is something that we are working with the Department on.

Mr. YOUNG. Thank you very much. Mrs. Bouquard?

Mrs. BOUQUARD. Thank you very much, Mr. Young.

I certainly appreciate our panel today. They have certainly given us some very valuable insight.

Mr. Matson, I appreciate your statement that we should move on to the goal of commercialization. Without this goal in front of us, and proceeding in piecemeal fashion, I am afraid that we are not really being too realistic with what we expect from our fusion program as directed by the Congress under the leadership of Congressman McCormack.

Also, I share with you your doubts of the wisdom of delaying the alternative confinement systems relative to our tokamak developments.

Last year, a panel of EPRI experts concluded that the fission-fusion hybrids appeared to be the most practical first application of fusion. They contended also that the hybrids offered a technology that is easier and potentially more competitive new energy option than fusion electricity generation.

Would you concur with that assessment?

Mr. **Matson**. We at Public Service, in particular, are rather positive on the fusion-fission hybrid. We do feel it is a very logical step that could be taken to get a practical earlier use for fusion than the longer term fusion stand-alone electricity producer.

It is, we feel, a very positive way to use the neutrons and in fact to have a machine, the hybrid machine, that could produce energy and also be a net producer of fuel and that could support other fission reactors that the utilities have and will have in the future.

So we are positive as far as the fusion-fission hybrid. I might add that EPRI is taking a more positive view, I believe, on the fusion-fission hybrid, also.

Mrs. **Bouquard**. So you feel it will be a more competitive new energy option?

Mr. **Matson**. Well, I think it has a possibility to be. There are those who look upon the hybrid as a competitor to, for instance, a breeder. We don't look at it so much that way, from the utility perspective. I think we are looking at it more as a means to enhance our capability to generate additional fuel for fission reactors and also a positive way to introduce the fusion concept at an earlier time.

Mrs. **Bouquard**. What do you envision as the first commercially viable application of fusion energy?

Mr. **Matson**. That is a good question. I think it depends upon what may be the Nation's biggest need. The way we are going with the fission program it possibly will not be fissionable fuel. There is a possibility, of course, that if we are severely impacted by, say, by the Middle East on liquid fuels, petroleum, the application, we may have to go to, and hopefully not in a crash kind of fashion, but we may have to go toward hydrogen, producing hydrogen and then, downstream, liquid fuels.

In the utilities right now, we are still looking upon it as an electricity producer, electric energy.

Mrs. **Bouquard**. Let's say we are able to reasonably fund our fusion programs. What is your guesstimate of when we can make fusion viable, commercially viable, as a source of energy?

Mr. **Matson**. Commercially viable. Now, I think maybe we have to define the concept of commercially viable.

Mrs. **Bouquard**. When can it enter the marketplace competitively?

Mr. **Matson**. Entering the marketplace competitively; I am hopeful that that would be within the first quarter of the next century, a real commercially competitive kind of objective.

That would require, I think, looking at and meeting the goals in the intent of the Fusion Energy Act, which as I say, are viable. We think those are very viable goals and objectives. There is some perturbation, obviously, in the funding, and I think we have to roll with those punches, But those goals and objectives, I think, still stand out in our minds.

Mrs. **Bouquard**. That is why I say if we had a reasonable level of funding.

Mr. **Matson**. Right. With a reasonable level of funding, I think we are in that scenario of, hopefully, the first quarter of the next century.

Mrs. BOUQUARD. Thank you very much.

Dr. Ohkawa or Dr. Gilleland, to what extent does the modification of the Doublet III vacuum vessel depend upon negotiation of the extension of the present United States-Japan agreement?

Dr. OHKAWA. When we were in Japan in February of this year, they were very interested in participating in relation to the $70 million 5-year agreement between DOE and JAERI. They have not gone through the formal government channels, but they are trying to—not trying to, they will—put on some funding in the next Japanese fiscal budget.

Mrs. BOUQUARD. When do you expect the modified device to be ready for research operations?

Dr. GILLELAND. We would install it in late fiscal 1984. It could be done earlier, but given the funding profiles as they are set now, I would say late fiscal 1984. It would take us about a year to be on the air again doing research, so it would be 1985.

Mrs. BOUQUARD. Do you think in any way the results obtained from the modified device would be preempted by the JET device?

Dr. GILLELAND. Not really. If we are funded to go according to that schedule, then because we are using hardware which has been proven, the heating systems, diagnostic systems, and we are using a basically proven device, the actual physics will probably come out of Doublet III first.

Also, there are complementary aspects to the two projects, particularly with regard to impurity control. So, no, I do not think we will be.

Mrs. BOUQUARD. What are the parallels with the JET device?

Dr. GILLELAND. They are both large plasmas. They both have large D-shapes to the plasma. In fact, I think they have been our biggest fans because we have done a great deal to prove their design.

Again, we are hoping, however, that we will be—I don't know whether they will be our fans or not—but we will be a few years earlier in the actual research in the big D, which of course is a machine which has a plasma which is about halfway between the size of the current machines and the actual reactor.

I define the actual reactor as those designs which are represented by FED or the Japanese FER. In a recent survey there was a discussion of the most important machines in the eighties to the United States and Japanese programs, and certainly in the large tokamak arena, the United States and Japan both stated that the TFTR, JT-60, and Doublet III were all very important machines to the program.

Do you want to add anything to that, Tihiro?

Dr. OHKAWA. No, thank you.

Mrs. BOUQUARD. Thank you very much.

Dr. Repici, in Dr. Bussard's prepared statement, he says—and this is kind of refreshing, something we don't hear very much—that you really don't want any Government funding. If this is the case, how can we help you here? [Laughter.]

Dr. REPICI. Thank you, Madam Chairman.

Mrs. BOUQUARD. Then why are you here?

Dr. REPICI. I tried to address that. The one reason I am here is to say that if we are successful, then you have decisions to make, and we relate to those decisions. I think, because I am an outsider with no Federal money and because of my personal experience at the OMB with the DOE fusion program, that I can say things that are positive about the U.S. fusion program and the goals of this act without bias or alternative agenda. There is a certain amount of credibility, quite candidly, attached to my statements.

There is also a self-serving role as to why I am here. There are certain policies within the U.S. Government that simply do not let private companies have access to taxpayer paid information. I have raised that issue with the staff, and it is not necessary to go into detail here, but you have funded the U.S. fusion program, and I think the goal of the program is not that we have DOE fusion but that we have a fusion success and somehow that that technology be made available for all of us.

Now, both Tihiro and I have a private enterprise dimension to all of this, he, in part of his project and for me in my entire project. If we are going to do well for America, I think, quite candidly, the investment that the taxpayers have made should be open to any credible American company.

But that is an issue that takes time to work. That is not done by fiat, and I recognize that.

Mrs. Bouquard. Well, if you are successful within the next 5 to 6 years, what impact do you see that this will have on the U.S. fusion program?

Dr. Repici. Quite a substantial impact. What I am hoping is that we do not make the mistake that we made when the fission program was successful. Well, my heavens, if private industry is doing it now, we can shut down the AEC's activities in the fission work, except for the Admiral's work.

The complexion of the DOE fusion program will change. It is not clear that a tokamak would be the best mechanism to generate fusion power. We believe it is the one that will happen soonest in the parameters that are achievable with today's technology.

The complexion of the DOE would change and, hopefully, it would exploit the success achieved by INESCO and would also look into some of the alternatives that might make better products in the longer run.

There is a key element, though, Mrs. Bouquard, and that is one of the other reasons for my being here. The U.S. program should recognize, and I think the participants do, that we exist and we are part of the U.S. program and that it truly is a U.S. program, not just a DOE program.

Mrs. Bouquard. How would you sum up the way that we could best benefit from your success?

Dr. Repici. Well, I think it is very clear how you could benefit from the success.

Mrs. Bouquard. Our overall program.

Dr. Repici. There is a tremendous amount of work that has yet to be done on blankets. The program I outlined to you today, Mrs. Bouquard, was essentially to generate neutrons. We have not touched yet how we are going to use those neutrons. They have to be thermalized in some blanket. The power has to be extracted.

You asked some questions as to whether hybrid is best. I have alluded to alcohol production, to synthetic fuel production, to cheap steam. Those are all technology issues which fit very nicely into the making-fusion-happen aspect of the Fusion Engineering Act. I see quite a role for the U.S. program.

Mrs. **Bouquard**. Thank you very much.

Thank you, Mr. Chairman.

Mr. **Young**. Mr. Lowery?

Mr. **Lowery**. Thank you, Mr. Chairman.

Dr. Ohkawa, the Magnetic Fusion Energy Engineering Act of 1980 calls for the operation of a magnetic fusion engineering device by not later than 1990 and the operation of a demonstration plant by the year 2000. The level of funding for magnetic fusion in 1982 did not have the 25-percent increase as outlined in Public Law 96-386. The increase, in reality, was less than 5 percent. The $444 million budgeted by the administration for magnetic fusion for fiscal year 1983 is 11 percent below the 1982 dollars, and that is in constant dollars.

Now, the cutback has put the Elmo Bumpy Torus-P program in jeopardy and could cause a stretchout of the MFTF–B program. My question to you is, Do you feel that it is appropriate or prudent to, so to speak, put all our eggs in one basket with the funding emphasis on the development of tokamak, and do you feel that the development of this technology alone will attain our goals that we have set in the 1980 legislation?

Dr. **Ohkawa**. Well, as I said in my testimony, the program is a well balanced one. We are not putting all our eggs in one tokamak basket. You have a mirror program, and there is the bumpy torus operating. There are pinches at Los Alamos. We have a balanced program.

To get back to the accelerated fusion development program, we have to have about, roughly speaking, a 20- to 25-percent a year increase in budget.

Across the ocean, the Japanese Government is in the same situation. They too have a tight budget. Despite that, the Japanese program fusion budget increased 15 to 20 percent this fiscal year, starting in April. So that shows the Japanese are very serious about the development of fusion. They are planning to have a fusion experimental reactor in the 1992–93 period of time.

Many of us were there in February, including DOE people. I do not like to hear the joke that probably we will end up importing fusion reactors from Japan. So I strongly urge that the fusion program be expanded so that we can catch up lost ground in the past year or two.

Mr. **Lowery**. And meet our goals.

Dr. Ohkawa, will it be possible for the modified Doublet III device to achieve ignition with deuterium-tritium plasma?

Dr. **Ohkawa**. No. The Doublet III is designed to use only ordinary hydrogen to save cost and time. It will simulate the conditions with ordinary hydrogen, but we have no plan for putting in deuterium and tritium. That experiment will be done in TFTR.

Mr. **Lowery**. So you are not anticipating that it will serve the role of a miniature fusion engineering device? You do not see that happening with Doublet III?

Dr. **Ohkawa**. No.

Mr. **Lowery**. Could it fill that role?

Dr. **Ohkawa**. Yes. This will simulate the core of a fusion engineering device so that we can learn how to control, how to handle these hot plasmas which are carrying the large plasma current. So that will be sort of a simulator of the FED core.

Mr. **Lowery**. Is that the limit to which you think Doublet III will go, that simulation?

Dr. **Ohkawa**. Obviously, the simulation, but also, we are planning to have the tokamak improvement program in there so that the tokamak will eventually become steady state, not pulsed. Those experiments must be done in the kind of plasma which will be used in the FED core.

Mr. **Lowery**. From your answers to Mr. Young's questions on the OHTE, it is obvious that you are committed to the reversed field pinch concept with the private sector investment that has been made.

What, specifically, are your goals with that program and within what time frame would you hope to achieve them?

Dr. **Ohkawa**. The first phase for the program is 3 years. In each different geometry, such as pinches, we have to establish empirically how well the plasma is confined and how much plasma will be confined; in other words, beta and confinement time.

So, in 3 years, we will do the physics experiments, and if the physics experiments indicate, by scaling them up slightly not in physical size but in plasma current, if we can reach the reactor-like plasma, that will be our plan for the second phase.

But since we just finished the first year of the experiments, we are not going to have the decision whether to go to the second phase or not until about a year and a half from now.

Mr. **Lowery**. A good question to all of you. If you were king, and I guess my definition of king is you are the Congress and the President all rolled into one, and if you were to approve additional funds to restore some of the projects for the fusion program, what would your order of priorities be? John, why don't we start with you and go down the table?

Dr. **Gilleland**. I don't pretend to possess that studied judgment in that I am a man who spends all his time in the laboratory at LaJolla.

Mr. **Lowery**. You approach it from a micro——

Dr. **Gilleland**. Yes. I happen to believe that the tokamak will evolve into a relatively simple and elegant reactor. I spent a year working for John Clarke, more or less, as executive director for the FED activities, and so, of course, my order of priority would be to move fusion truly into the engineering phase, and for that there is a requirement for a large device such as FED. FED as presently designed may not be the ultimate answer, but I found that one can design a device which will generate sustained large amounts of fusion power and that one can design a device which can accommodate innovations as they come; for example, the current drive possibilities which allow one to push the current around in the tokamak without an ohmic heating system.

This is a wordy way of saying that there are very promising bits of data now which say that we can eliminate systems from the tokamak and even further enhance its elegance. And so I think it is not premature to push ahead now with an initial reactor based on the tokamak concept, and that is where I would personally put my priority.

I could go down the list, but I think I would be in trouble as I got into lower levels because I cannot differentiate the promise of one system from another too well. I think they are all important. It is important to have a balanced program because some of these bottles will indeed someday be more appropriate than others as reactors. I think the main thing to say about fusion is that the results across the board are encouraging; the studies are encouraging; there is still this ultimate promise which I fix my dream upon, and that dream is that someday there will be an energy source which is highly acceptable environmentally and has almost no fuel cost and, although it is a high technology system, it is simple and it is elegant.

That is my dream, and that is how I am spending my life.

Mr. LOWERY. And creating the sun.

Dr. OHKAWA. As I said before, the present program is a balanced one; it is broad based. But that does not necessarily mean that we don't have a focused approach in each element. For example, in the tokamak area, most of our experts around the country agree that we are focusing on the improvement of the tokamak, such as to steady state.

So I would keep the similar balance if the funding is increased.

Mr. LOWERY. I forgot, in my definition of king, it is not only the Congress and the President but it is also the Director of OMB. [Laughter.]

Mr. MATSON. Well, now that I have all this power, hopefully not to be an autocratic king and knowing that there are other needs of the kingdom, I think I would look upon the action taken by the Congress as being rather astute in the overwhelming passage of the Fusion Energy Act and in the goals and the objectives that were included in that act.

I would probably want to have, as king, a pretty well developed plan as to how to get from here to there, basically, the there being what the act would provide the Nation in the form of essentially inexhaustible energy.

I agree with the previous comments on the balanced program. In particular, I think we don't want to center on the tokamak alone. As was mentioned in my testimony, the mirror, EBT, some of these other programs have been somewhat behind, and it is acknowledged that if one of these alternatives is better, we would certainly want to know about it. So I think I would want to have, as king, enough funding to be able to continue a balanced program to realistically evaluate the alternatives and be able to select downstream what would be the best approach to meet the objectives of the act in a reasonable amount of time as the act, I think, would like us to do. I think that is the way I would approach it.

Dr. REPICI. Mr. Chairman, since I am apparently much closer to engineering problems, if we are successful, the questions for me are ones of material data. It is most critical, as I go from the stage of creating the light bulb to making the lampshade, which uses that radiation, that the Fusion Materials Irradiation Test facility, the FMIT, be available. The FMIT, or similar device, would be important since it would supply the kinds of engineering data that I will need when I, hopefully, get there.

Mr. LOWERY. One final question. Mr. Matson, in the last months, utilities have stopped construction of quite a few nuclear powerplants largely because of the costs, the regulatory problems, and lower forecasts in demand. In fact, I would say construction of the powerplants in general, including nonnuclear, have at least slowed down.

It seems that the utilities are favoring smaller scale, lower cost facilities. Other than your comment in your testimony about making a national commitment to commercialization of fusion, are there other steps that we should be taking to make sure that the fusion program develops low-cost, economical systems?

Mr. MATSON. I think, as far as—you mentioned size of units. I think that is going to be, in the future, when utilities are looking for power options, an important factor. The items you pointed out regarding the current state of utilities are very true.

Mr. LOWERY. Do you think it is temporary?

Mr. MATSON. I think it is temporary, yes. I think that is going to turn around. I really feel that, as we have in the past, our Nation's capacity will surface. We will again revert to a strong industrialized base. I think we have in the past and I do not see any reason why we should not in the future.

In order to do that, I think we are going to have to have the capacity in electrical power to serve that need. So I think that will come back.

So it is a matter, I think, of the energy options that we have to look toward in the future, notwithstanding the fission reactor problem. I think that, in comparison, the fusion program has a great deal of advantage that the utility can look toward as an energy option downstream, and that could be—I emphasize "could be"—regardless of size because there are some utilities, who would want the smaller size fusion option; there are those who are going to want the larger size option, depending upon their particular needs and system characteristics.

So I think that to us looking at it from the utility perspective, it is still the attractive, inexhaustible fuel supply option that we would like to see downstream.

Mr. LOWERY. Energy abundance instead of managing scarcity.

Mr. MATSON. Right.

Mr. LOWERY. Thank you, Mr. Chairman.

Mr. YOUNG. Gentlemen, on behalf of the chairman and the members of the subcommittee, we want to thank you very much for your participation this morning and your organizations for the fine testimony that we have been able to put in the record. We look forward to having you back again next year, and that we will move on into the development of this fantastic power source. So I want to thank you very much for your attendance this morning.

Thank you.

I will now call our second panel of witnesses. This panel will consist of the Honorable Mike McCormack, Mr. Ed Kintner, and Dr. Stephen Dean.

Mike McCormack, as I am sure everyone here today knows, is a former chairman of this subcommittee and was the author of the

Magnetic Fusion Energy Engineering Act of 1980. Mike, it is always a pleasure to see you and we will be looking forward to hearing your provocative testimony.

Mr. Ed Kintner is another familiar face to members of this subcommittee, having been Associate Director of the Office of Fusion Energy for a number of years. Ed, as we are aware, felt it was necessary to resign his position a few months ago because of policy differences with the administration with the magnetic fusion budget. We will be interested in hearing his perspective of the program.

Finally, I would like to welcome back Dr. Steve Dean, president of the Fusion Power Associates and one of the real leaders of the fusion community.

Welcome, gentlemen. As I understand it each of you has a statement and then Mike will want to make some summary statements before we commence with the questions. So, Mike, it is our pleasure to have you this morning and please proceed.

STATEMENT OF MIKE McCORMACK, ENERGY CONSULTANT

Mr. McCormack. Mr. Chairman, good morning to you and Mrs. Bouquard and Mr. Lowery and Mr. Hollenbeck. It is certainly a pleasure for me to be back with the subcommittee, even on this side of the witness table.

With your permission, Mr. Chairman, I would like to submit my prepared testimony and additional material for the record.

Mr. Young. Without objection it is so ordered.

Mr. McCormack. First of all, I want to express my appreciation to you and to the members of the subcommittee for inviting me to discuss this Nation's policies and programs for magnetic fusion. It is a matter, as you know, of great concern to me, and also to Mr. Kintner and Dr. Dean who join with me today in presenting this testimony.

As you have said, Mr. Chairman, I will make a brief presentation, followed by Mr. Kintner and Dr. Dean, and then I will have a few summary remarks.

We will be brief and we are, of course, anxious to respond to questions that you or the other members of the subcommittee may have.

I think, Mr. Chairman, a bit of background may be appropriate at this time. For those of you who were not involved, this whole campaign to move fusion from a research concept to a program for power development started from many places at many times. For me it started when I was appointed to the Joint Committee on Atomic Energy in 1973, about the same time that Dr. Robert Hirsch became director of the fusion program for what was then the Atomic Energy Commission.

Dr. Hirsch and I set out on a campaign to expand the program. We agreed, and the Congress supported us in our belief, that this Nation could convert the concept of magnetic fusion energy into reality within perhaps 25 years with an adequately funded and coherent program of research, development, and demonstration, which obviously includes both research and engineering of materials testing.

When the Department of Energy was formed in 1977, Dr. Hirsch resigned, and Mr. Kintner replaced him as director of our fusion program. They had already been working together with me and the members of this committee and with other committees of the House and Senate to increase the funding levels for magnetic fusion research from about $30 million in 1973 when we started, to about $400 million in 1979.

Our goal was always the demonstration of magnetic fusion electricity by about the year 2000. During the late 1970's this subcommittee committed itself to eliminating unnecessary projects in the fusion program. Some of you were here when we entered into a protracted debate about how we were going to convert the program away from just a research-only concept into a goal-oriented program for energy production at the earliest realistic date.

The Fusion Advisory Panel was formed in 1979, chaired by Dr. Hirsch and composed of some of this Nation's outstanding fusion scientists, along with equally brilliant engineers and industrial executives. The report of the Fusion Advisory Panel in 1980 led us in this subcommittee to draft the Magnetic Fusion Energy Engineering Act in 1980. As a result of our introducing this legislation and advising the world that we were serious about enacting it, the Department of Energy created its own study panel under the Energy Research Advisory Board, directed by Dr. Sol Buchsbaum.

I think it is important for all members of the House Committee on Science and Technology today, and all the Members of Congress who are not familiar with it, to recognize that three committees; first of all the Foster committee, a Department of Energy Committee which preceded the Hirsch committee, the Hirsch committee, and the Buchsbaum committee—all made up of some of the Nation's most outstanding scientists, engineers, and corporate executives—agreed that the time had come for this country to move forward with a program of fusion engineering development and materials testing. And, the Hirsch panel and the Buchsbaum panel, which were still functioning at the time we were working on the legislation, each agreed that it should be possible to have a fusion electric demonstration plant on the line by about the year 2000. It was this confidence, expressed in these reports, and the concurrent success during that period of time of our plasma physics research in our various research laboratories that convinced us that we should go ahead and enact this legislation with the confidence that we would demonstrate scientific feasibility in our existing laboratories with machines under construction in the late 1983 to 1985 period.

It is also important to remember that this legislation was passed with only seven dissenting votes in the House, and by unanimous voice vote in the Senate. It had strong bipartisan support from both bodies and it was based on the conviction that we should not wait until after we had scientific feasibility demonstrated, but that we should start now with our engineering program so there would not be a 5-year gap after we had scientific feasibility, that we would not stand around in 1983 or 1984 or 1985 and say, "gee, what should we do now."

It is significant to note that within only a few weeks after the passage of the Magnetic Fusion Act, Japan, Russia, and the European Economic Community each initiated reviews of their fusion programs, and within a few months all three decided to accelerate their programs in quite the same way that we in the U.S. Congress, that you in this subcommittee and I had agreed to accelerate ours.

Unfortunately, the Department of Energy and the Office of Management and Budget have decided to fundamentally ignore the law that we enacted, and to revert back to a "research only" policy for fusion, delaying the engineering intiatives called for in this act. Because of this unauthorized attempt at policy reversal, the United States is already falling behind in this all-important area of energy engineering development.

I have several copies of Energy Daily here. One points out that we may be buying our fusion machines from Japan because they are already moving more aggressively in this direction.

I submit, Mr. Chairman, that the time has come for the Congress to insist that the spirit of the fusion law be followed and that at least a small part of the funding planned for fusion engineering development be approved for fiscal year 1983.

Mr. Kintner and Dr. Dean and I are joining today in encouraging this subcommittee to increase the authorization level for magnetic fusion research and development and demonstration for fiscal year 1983 by 10 percent over the current level for 1982. This would mean increasing funding from $455 million, as it is today, to about $501 million for fiscal year 1983. You will recognize that this really only compensates for inflation. The additional $56 million over the administration's 1983 request would, we recommend, be apportioned as follows:

For the Center for Fusion Engineering, $10 million in addition to the money that is already there; although there is no line item for it in the budget, there is some money there.

For the FMIT which is absolutely critical for any program whatsoever in the Federal program, $15 million.

For the Elmos Bumpy Torus, $21 million. Contracts, as you know, have already been let and that has been zeroed out in this budget.

And, for the MFTF-B, $10 million additional to put it back on track.

Each of these projects is critical to having a coherent program. The first two are absolutely essential for engineering programs; the bottom two are essential for filling out our research program.

This, in a sense, Mr. Lowery, responds to the question you asked the previous panel.

I recognize that there are those that may hesitate to provide adequate funding at this time to proceed at the levels we recommend. I should like to point out that the law which the Congress enacted was built on very careful consideration of what was necessary to move forward with a successful program of fusion engineering development and materials testing, and the partially completed FMIT is an example of that.

The bill called for a funding level for fiscal year 1982 of 25 percent above 1981. At this level, it would have been $525 million this year instead of the $455 million we are spending now. And, it called a 25-percent increase above that $525 million for this coming fiscal year. So, if the law itself were followed, the funding level for

1983 would be $656 million. We are suggesting $501 million, which means that we are already below the recommended funding level for 1983 by $155 million, not counting inflation.

Now, we certainly sympathize with the budgetary problems that you and other Members of Congress face. Nevertheless, we insist that the funding levels that we are suggesting are essential to maintain the program and to give the program meaning. If we are going to be spending $444 million it is essential that we spend the rest to give the program meaning at all.

The increase that we recommend, to put it in context, is equal to what this country spends every 6 hours on imported oil. Our proposed funding for magnetic fusion for fiscal year 1983, a total of about $500 million, is equal to what we spend in 2½ days on imported oil. The entire fusion program for the next 20 years—the $20 billion that we propose for the entire program—is less than 2 percent of what we will spend for imported oil in that time.

As I sat here listening to previous testimony I looked at these beautiful pictures around the wall and I thought to myself that for about one-third or about one-fourth of what was spent on these space programs, this country can demonstrate the fusion program and provide an absolutely unlimited source of cheap and clean energy for all mankind for all time.

We are really not talking about a money problem; we are really talking about a priority problem. This is, in fact, what I think must be understood.

Now, Mr. Kintner and Dr. Dean will discuss the status of our fusion program as it now exists and what needs to be done in the near future to move forward into a program of engineering development.

Before they do, I have one additional thought I should like to make at this time. The Congress and most of you committed this Nation to one of the most important projects in its history when we passed the Magnetic Fusion Act of 1980. It was not a trivial thing. Most of the Members of Congress recognized it when they approved a 20 year, $20 billion program. Most of them comprehended the extraordinary value to this country—and to mankind—of developing this ultimate energy source, at the earliest possible date, for the people of this country and the world.

Since that time, several individuals—only a few—in the administration, and none of them directly responsible to the Congress or to the people of this country, and none of them appearing before this committee, but each of them established in a strategic position in the administration, have taken it upon themselves to undo the fusion engineering program that we in the Congress, supported by scientists and other experts in the Government and industry to recognized as being essential. What has happened is that this scant handful of individuals is attempting to abrogate the law that you wrote, and to totally disregard what the Congress has directed be done. The law that you passed has been ridiculed, and administration spokesmen, none of whom have appeared before this committee, have stated that fusion is just a research program; that that fusion power is perhaps 70 years away. Some of them claim, without any appropriate background, to be qualified to ignore and reject the deliberations of some of the world's outstanding scientists, as well as of the Congress itself.

I urge the members of this subcommittee, in spite of your difficulties with the budget, to remember the leadership that you provided in the past, and to remember that the people of this country are looking to you now for that same leadership. What you do on this subject during the next few days can have a profound effect upon the world in which your children will live.

Thank you very much.

[The prepared statement submitted by Mr. McCormack follows:]

STATEMENT OF MR. MCCORMACK ON MAGNETIC FUSION ENERGY RESEARCH, DEVOLOPMENT AND DEMONSTRATION

Good morning, Mr. Chairman.

I want to express my appreciation to you and to the members of the Subcommittee on Energy Research and Production for inviting me to discuss our nation's policies and programs for magnetic fusion research, development and demonstration. This is a matter of great concern to me, and to Mr. Edwin Kintner and Dr. Stephen Dean who join me today in presenting testimony. With your permission, Mr. Chairman, I will make a brief presentation, followed by Mr. Kintner and Dr. Dean, and then I will summarize. We will be brief; and we are, of course, anxious to respond to questions you and the other members of the Subcommittee may have.

Mr. Chairman, there is a bit of background which may be appropriate at this time. I was appointed to the Joint Committee on Atomic Energy in 1973, at about the same time that Dr. Robert Hirsch became director of the fusion program for the Atomic Energy Commission. Dr. Hirch and I set out on a campaign to expand the magnetic fusion program. We agreed, and the Congress supported us in our belief, that this nation could convert the concept of magnetic fusion energy into reality within perhaps 25 years with an adequately funded coherent program of research, development and demonstration.

When the Department of Energy was formed in 1977, Dr. Hirsch resigned, and Mr. Kintner replaced him as director of our fusion program. They worked together with me and the members of this Committee—past and present—and other Committees of the House and Senate to increase funding for magnetic fusion research from about $30 million in 1973 to about $400 million by 1979. Our goal was always the demonstration of magnetic fusion electricity by about the year 2000. During the late 1970s this Subcommittee committed itself to eliminating unnecessary projects in the fusion program and directing the fusion budget toward the goal of electric energy production at the earliest realistic date.

The Fusion Advisory Panel was formed in 1979, chaired by Dr. Hirsch and composed of some of this nation's outstanding fusion scientists, along with equally brilliant engineers and industrial executives. The report of the Fusion Advisory Panel in 1980 led us in this Subcommittee to draft the Magnetic Fusion Energy Engineering Act of 1980. As a result, the Department of Energy's Energy Research Advisory Board ordered a special study of our bill, directed by Dr. Sol Buchsbaum.

It is, I think, important for all members of the House Committee on Science and Technology today, whether they were members at that time or not, to recognize that three committees, each made up of some of the nation's outstanding scientists, engineers and corporate executives agreed that the time had come for this country to move forward with a program of fusion engineering development and materials testing, and the Hirsch Panel and the Buchsbaum Committee agreed that it should be possible to have a fusion electric demonstration plant on the line by about the year 2000.

It was the confidence, expressed in these reports, and the concurrent successes in plasma physics research in our research laboratories (at MIT and Princeton and Oak Ridge and Los Alamos and Livermore) that convinced us that we should enact this legislation. It is important also to remember that the legislation was passed with only 7 dissenting votes in the House, and by unanimous voice vote in the Senate. It had strong bi-partisan support in both bodies.

It is significant to note that within only a few weeks after the passage of the Magnetic Fusion Act, Japan, Russia and the European Economic Community initiated reviews of their fusion programs, and within a few months all decided to accelerate their programs in quite the same way that we in the United Stated Congress agreed to accelerate ours.

Unfortunately, the Department of Energy and the Office of Management and Budget have decided to ignore the law that we enacted, and to revert back to a "research only" policy for fusion; delaying the engineering initiatives called for in this Act. Because of this unauthorized attempt at policy reversal, the United States is already falling behind in this all-important area of energy engineering development.

I submit, Mr. Chairman, that the time has come for the Congress to insist that the spirit of the fusion law be followed; and that at least a small part of the funding planned for fusion engineering development be approved for fiscal year 1983.

Mr. Kinter and Dr. Dean and I are today joining in encouraging this subcommittee to increase the authorization level for magnetic fusion research development and demonstration for fiscal year 1983 by 10 percent over the current level for 1982. This would mean increasing funding from $455 million for this year to $501 million for fiscal year 1983. This, you will recognize, really only compensates for inflation. The additional $56 million would, we recommend, be apportioned as follows:

	Millions
Center for fusion engineering	$10
FMIT	15
Elmo Bumpy Torus	21
MFTF-B	10
Total increase	56

If there are those who hesitate to provide adequate funding for the magnetic fusion engineering program to proceed at the levels we recommend, I should like to point out that the law which the Congress enacted was built on careful consideration of what was necessary to move forward with a successful program of fusion engineering development and materials testing. It called for a funding level for fiscal year 1982 of $525 million rather than the $455 we are spending now; and it called for a 25 percent increase above the $525 for fiscal year 1983. Thus, if the law itself were followed, the funding level for fiscal year 1983 would be $656 million. We are suggesting $501 million, which means that we are already below the recommended funding level for fiscal year 1983 by $155 million, not counting inflation.

The increase we recommend is equal to what this country spends every six hours for imported oil. Our proposed funding for magnetic fusion for fiscal year 1983 is equal to about 2½ days of imported oil; and the entire $20 billion we project for fusion research, development and demonstration between now and the year 2000 is less that 2 percent of what we will spend for imported oil during that time.

Mr. Kintner and Dr. Dean will discuss the status of our fusion program as it now exists, and what needs to be done in the near future to move forward into a program of engineering development. Before they do I have one additional thought: Congress committed this nation to one of the most important projects in its history when it passed the Magnetic Fusion Act of 1980. Most of the Members of Congress recognized this when they approved a 20 year, $20 billion program. Most of them comprehended the extraordinary value to this country—and to mankind—of developing this ultimate energy source, at the earliest possible date, for the people of this country and the world.

Since that time, several individuals in the Administration, none of them directly responsible to the Congress or to the people of this country, but each of them established in a strategic position in the Administration, have taken it upon themselves to undo the fusion engineering program that we in the Congress, supported by scientists and other experts in government and industry recognized as essential. What has happened is that this scant handful of individuals is attempting to abrogate the law that you wrote, and to totally disregard what the Congress has directed be done. The law which you passed has been ridiculed, and Administration spokesmen have stated that fusion is just a research program; that that fusion power is perhaps seventy years away. Some of them claim, without appropriate background, to be qualified to ignore and reject the deliberations of some of the world's outstanding scientists, as well as of the Congress itself.

I urge the members of this subcommittee to remember the leadership that you provided in the past, and to remember that the people of this country are looking to you, now, for the same leadership. What you do on this subject during the next few days can have a profound effect upon the world in which your children will live.

Mr. YOUNG. Thank you very much, Mike.

Mr. Kintner?

STATEMENT OF EDWIN E. KINTNER

Mr. KINTNER. Thank you very much, Mr. Young.

I have a prepared statement which I would like to offer for the record and I would like to summarize.

Mr. YOUNG. Without objection, it will be entered as a part of the record.

Mr. KINTNER. For 5 years, as head of the U.S. magnetic fusion program, I came before this committee. Every year the committee showed its support for the program; either added some funds to the requested budget, or kept alive projects which had been recommended for recision. Then, under the leadership of this committee and its chairman, Mr. McCormack, the Congress enacted the Magnetic Fusion Act of 1980.

I proceed in my discussions from a basic point of view that energy is the most important secular question facing the future of the Nation. Its cost is already having a measurable effect on the economy, not only of the United States but of the Western World. Its geographical location and assurance of its availability dominates our diplomatic and military actions and plans.

Even so, the present circumstances with regard to energy are tenuous. Mr. Stark described it yesterday as "a house of cards." The energy problems are not solved using all available energy options. There is only one remaining option which can be added and that is fusion. If fusion were added, the future of energy would certainly be different. It is from that context from which I speak.

My purpose is to identify that two major programmatic decisions have been made during the several stages of the fiscal year 1982 and 1983 budget cycles which have changed, in a fundamental way, the character, direction and expectation of the U.S. program.

Whatever one thinks of the prospects for and importance of success, whatever one judges to be the importance of reducing Federal expenditures, these decisions will have long-term implications.

Fusion has been worked on for about 30 years. It is often said that we have made very little progress in 30 years. I think it is important to remember what Mr. McCormack said, that very little money was spent, the effort was very small, on a laboratory scale until about 8 years ago.

The T-10 and the Princeton Large Torus, the two machines on which the present confidence with regard to fusion rests, have been operating less than 6 years. The TMX experiment at Livermore, which gives us confidence that there are more than one way in which plasmas can be confined at power reactor conditions, has operated only a little over 2 years.

So, progress has, indeed, been rapid and significant. As a result of this progress there have been three high level reviews which Mr. McCormack referred to, I would like to quote very selectively from the reports of those reviews. First, the Foster committee said:

> There are now in view only a few essentially inexhaustible energy sources which can in principle contribute to the solution of the long-range world energy problem. A program based on fossil hydrocarbon fuels, though necessary for the near-term, provides only a limited solution.
>
> Since fusion energy is one of a severely limited number of possible alternatives, the first objective of the program must be to determine the highest potential of fusion as a practical source of energy. . .

> It is too risky at this time to concentrate just on the physics experiments and delay to a later time considerations of downstream engineering problems.
>
> There must be a major increase on engineering problems to provide the basis for proceeding to engineering development and the subsequent choice of an engineered prototype reactor.

This report to the Foster committee was translated into a policy statement for fusion energy by the Department of Energy, which said:

> There is no lead time to spare: if fusion energy is to be available when it is needed—the research and development program, rigorously directed toward the goal of commercial utility, must be undertaken now.

That report also established the milestone date of 1985 by which the alternate concepts, mirrors, elmo bumpy toruses, could be compared in some sort of a meaningful way with tokomaks before proceeding further with development of fusion energy.

Then, in late 1979 and early 1980, Mr. McCormack and this committee established a group of experts chaired by Dr. Robert Hirsch to review the program. They concluded as follows:

> The time is now for an engineering thrust centering on an engineering test facility.
>
> Our panel believes that fusion can be made commercial by the year 2000 if a national commitment is made soon.

Then, later in 1980, the Department initiated a further review by a very distinguished panel of experts, perhaps the strongest panel of scientific experts assembled for review of a program of this kind, the so-called Buchsbaum Panel. Its major recommendation was:

> The magnetic fusion program can, and should, embark on the next logical phase toward its goal of achieving economic feasibility of magnetic fusion. To this end a broad program of engineering experimentation and analysis should be undertaken under the aegis of a Center for Fusion Engineering.

Following that, both Europe and Japan carried out reviews which, essentially, supported the basic principle that fusion could now be assumed to be scientifically feasible and it was time to begin seriously the engineering development phase.

Congress then passed the Magnetic Fusion Energy Engineering Act of 1980 which said:

> The energy policy of the United States must be designed to insure that energy technologies using essentially inexhaustible resources are commercially available at a time prior to serious depletion of conventional resources.
>
> To insure the timely commercialization of magnetic fusion energy systems, the United States must demonstrate at an early date the engineering feasibility of magnetic fusion energy.
>
> It is, therefore, declared to be the policy of the United States and the purpose of this Act to accelerate the national effort in research, development and demonstration activities related to magnetic fusion energy systems.

The act and the ERAB recommendations were essentially in consonance with regard to the basic timetable and the basic methods of proceeding. The strategy was to embark on the engineering technology phase, its centerpiece being a fusion engineering device. It should be completed by the year 1990 so that a formal assessment could be made and, if things were going well, by the year 2000 a demonstration of practical usefulness could be concluded.

That, as you have heard from several other members of the panel before us, seemed a logical timetable and seemed a reasonable expectation for a well-organized, effective program. It is now an irony of history that this planning, this consensus that was achieved over a period of years, has now been turned back.

The expenditures for fusion energy have been sharply reduced; the fiscal year 1983 budget before you is 24 percent below the 1977 budget in real terms, 1977 was the peak budget year from the standpoint of program buying power.

Now, I would like to point out where the two fundamental decisions were made. The first one was to defer for an undetermined period, the intentions and actions required by the act of 1980. The second one was to delay, again for an indefinite period, the Mirror Fusion Test Facility which would have provided the basis for comparison in the mideighties of the mirror system with the tokamak and other toroidal systems.

Further, the plan to increase industry involvement which was a centerpiece of the Magnetic Fusion Engineering Act—to increase the industrial involvement in fusion development in a deliberate way—that will be postponed indefinitely, and the industrial and economic benefits of the high-technology development which would be involved in that aspect of the program would be delayed as well. But, the most important single factor, in my judgment—having been there when it happened—is an intention implicit in the fiscal year 1982 and 1983 budgets—to revert the program back to a science-oriented mode.

The persons who have shaped that policy have stated their purpose publicly and privately and their actions support their words. The orientation toward making fusion practical and useful which began 8 years ago is now being rescinded. Thus, what is happening goes well beyond budget policy or budget levels alone.

It goes beyond budget levels even with regard to the Office of Energy Research itself because both the high energy physics programs and the basic energy science programs have received increases, whereas magnetic fusion—the other large program in that budget—has been decreased. The root cause of this, as I see it, is a lack of perception of the true significance of energy and the problems of energy in the moderate and long term to which fusion must make a measurable contribution.

All of this could be easily understood if the program were failing technically or organizationally, but these recent actions have taken place, as you heard yesterday and today, in a circumstance in which significant progress is being made in almost every aspect of U.S. fusion program as well as in the rest of the world.

It is difficult to understand why responsible officials would want to turn away from a highly successful program looking toward making the last, the ultimate energy resource in the universe available. It is especially difficult in view of the fact that there are continuing difficulties developing in other energy sources and, for the first time, we see hard evidence of two threatening problems of the use of any fossil fuel: acid rain and carbon dioxide in the atmosphere.

In any case, $440 million is a great deal to spend on any purely scientific program. If, in fact—and I repeat, if, in fact—this is to be a science-oriented program without a mission, without a goal, without some practical social usefulness, then that is far too much money. If, on the other hand, the program has a purpose and a goal, and is working successfully toward that goal in the present circumstances, then in my judgment, $440 million is not sufficient, notwithstanding the budgetary difficulties that this Nation faces.

In an important sense, the real question is not budget levels, but intent and commitment. That is what the act gave us for the first time: a purpose, a plan, and a national commitment. That is what we have now lost by these two actions. The program is now a group of projects. They will spend the money. It is, as I have said, a little bit like a chicken from which all the bones have been removed—it weighs just as much but it does not fly very well. That is exactly what has happened to the fusion program.

What are the effects of this decision not to proceed deliberately and hopefully?

The first one is that the date on which fusion can be counted on to mitigate the many and increasingly intractable problems of energy will be postponed at least year for year. We have already lost 2 years, based on the testimony of DOE officials yesterday. I conclude that 2 more years are going to be lost before a decision is going to be reached as to whether to proceed or not.

The second loss is that the consensus strategy which has been achieved and which was a part of the act is also in grave danger of being lost. Such consensus does not happen overnight. It took many years to put together the program as it existed and then gain the support that it had, including congressional support. When that is withdrawn, even for a year, then the likelihood of the program coming apart into individual pieces is high. In other words, this is not simply a matter of postponing the program for a year or two; it is a matter of a threatened loss of the whole perspective.

Third, U.S. world leadership in fusion, which has allowed us to work effectively within the total world program to strengthen those world programs in a cooperative effort, will be weakened.

Finally, the development side, the technological side, in which we were pushing the state of the art on many fronts. will now be slowed, and the possibility that that effort would inspire industrial innovation will be lost. This is especially true since the engineering technology program would have been carried out mainly in industry.

Thus, within less than a year, without internal or external reviews of any consequence, on the basis of judgments of individuals with no previous experience or commitment to fusion, the consensus judgment of the Congress, and three high-level reviews has been overridden.

It is an irony of history—in my view a tragic one—that the United States finds itself, having arrived at recognized world leadership in an important technology with great implications both for this Nation and the rest of the world, unable to find the resources, either organizational or financial, to carry through with previously characteristic American will and vitality, a program which has been carefully laid out over the last 8 years.

Sidney Harris has said,

> An idealist believes the short run doesn't count. A cynic believes the long run doesn't matter. A realist believes that what is done or left undone in the short run determines the long run.

Nowhere is that going to be more true than in energy policy.

It may really be that this Nation cannot afford to carry out, in a deliberate and hopeful way, the consensus plans laid out for fusion development; but no one should doubt for a moment that this will not be without lasting consequences. The future will appear different in 10 years and it will be different within 25. Where there is no vision the people perish.

Thank you very much, Mr. Chairman.

[The prepared testimony of Mr. Kintner follows:]

STATEMENT OF
EDWIN E. KINTNER
TO THE
SUBCOMMITTEE ON ENERGY RESEARCH AND PRODUCTION
OF THE
HOUSE COMMITTEE ON SCIENCE AND TECHNOLOGY
MARCH 24, 1982

My purpose is to identify as clearly as possible that two major programmatic decisions have been made during the several stages of the FY 1982 and FY 1983 budget cycles. These decisions which have changed, in fundamental ways, the character, direction and expectation of the U.S. magnetic fusion energy program. Whatever one thinks of the prospects for and importance of success in fusion development and whatever one judges to be the importance of reducing federal expenditures these decisions will have important long-term implications. They deserve to be thoroughly understood as to their origins and effects by those parts of the Government which have responsibility for such matters, and by the public generally.

To properly appreciate the events of this last year, it is necessary to understand the general history of fusion development. Magnetic fusion originated as a science research program in the early 1950's. It worked along slowly at funding levels of about $30 million a year for many years, accruing preliminary understanding of a new scientific subject--plasma physics. At the time of the energy crisis in 1973, it had made sufficient progress to justify a major role in the plan for new energy research and development known as Project Independence. That plan envisioned increased financial support for fusion, a broadening of the physics investigations, beginning steps towards development of the engineering technology required to make fusion practical, and a goal orientation and schedule. Its impetus resulted in budget levels for magnetic fusion increasing to $316 million in FY 1977.

Since that time, real budgets through FY 1983, after adjustment for inflation, have decreased 24 percent. Nevertheless, with support of these resources, the United States established laboratories, facilities, and program strategy which gave it world leadership in this field--a leadership which had been exerted previously by the Soviet Union. The experimental results from the strengthened program gave greatly increased confidence that the fusion process hitherto known only in the Sun and stars, could, in fact, be made useful on Earth.

Thus, although fusion research is 30 years old, only in the last eight years has it been of significant scope. The medium scale experiments, T-10 in the Soviet Union and the Princeton Large Torus (PLT) have been operating only six years. During that time the program was searching intensively for a strategy suited to it, one which recognized its uniquely long-term, broadly based nature, and its lack of military motivation or early financial return.

As a result of recognition in recent years of increasing problems of energy supply and environmental effects, the impressive scientific progress, and the generally held judgment that scientific feasibility was now assured, three high level scientific reviews were convened to help establish the appropriate future course for fusion development.

In 1978, the new Department of Energy as one of its first acts established an Ad Hoc Experts Group on Fusion, chaired by Dr. John Foster, former head of Research and Development in the Department of Defense, and made up of a number of distinguished scientists and engineers, to review the program and report its findings and recommendations. The Experts Group arrived at a number of important conclusions; in particular: (Emphasis from here on is the author's).

> "There are now in view only a few essentially inexhaustible energy sources which can in principle contribute to the solution of the long-range world energy problem. These include fusion, fission (with some type of breeder), and solar power. A program based on fossil hydrocarbon fuels, though necessary for the near-term provides only a limited solution.
>
> "Since fusion energy is one of a severely limited number of possible alternatives, the first objective of the program must be to determine the highest potential of fusion as a practical source of energy ...
>
> "...There is an urgent need to answer the questions concerning feasibility and the momentum of the program is an asset and should be maintained.
>
> "In our judgment the proper strategy should optimize the chances of determining the highest potential for a commercial fusion energy source at the earliest practical date.
>
> "...it is too risky at this time to concentrate just on the physics experiments and delay to a later time considerations of downstream engineering problems.
>
> "...there must be a major increase in emphasis on engineering problems to provide the basis for proceeding to engineering development and the subsequent choice of an engineered prototype reactor."

The Ad Hoc Experts Group recommended that the Department of Energy.

> "Lay the groundwork for one or more engineering test facilities (ETF) to be committed as soon as practical after the potentially competitive designs are identified.

Based on the recommendations of the Ad Hoc Experts Group, the Department issued a Policy Statement for Fusion Energy, which stated:

> "...Successful commercialization of fusion could provide an energy resource whose ultimate fuel (deuterium extracted from water) is cheap and essentially unlimited, and whose byproducts would pose much reduced environmental problems compared to coal and fission power. But there is no lead time to spare: if fusion energy is to be available when it is needed--the research and development program, rigorously directed toward the goal of commercial utility, must be undertaken now.
>
> "...The goal of fusion research in the Department of Energy is to develop the highest potential for employment of fusion energy."

In early 1980, the Chairman of the House Subcommittee on Energy Research and Production, House Science and Technology Committee, Congressman Mike McCormack of the State of Washington, organized a Fusion Advisory Panel to hold special hearings and advise him and his Committee on the status of the U.S. fusion program. The Panel was made up of a number of distinguished scientists both from within and without the fusion program. Their conclusions were, in part:

> "The Fusion Advisory Panel reaffirms its previous position:
>
> "- There has been very significant recent technology progress in fusion research.
>
> "- The time is now for an engineering thrust centering on an engineering test facility.
>
> "- Our panel supports the present DOE balanced research and development program.
>
> "- Our panel believes that fusion can be made commercial before 2000 if a national commitment is made soon."

In 1980, the Department chartered another thorough scientific review of the magnetic fusion program. This panel was headed by the Chairman of the Energy Rsearch Advisory Board, Dr. Solomon Buchsbaum, and its members were selected from a broadly experienced group of scientists and engineers. The Buchsbaum Panel has been characterized as the most powerful group of its kind every assembled for a scientific program review.

The Buchsbaum Panel spent a total of eleven days in plenary session in Washington and the major fusion laboratories, and its members visited the other magnetic fusion activities and received testimony from the general public. Its conclusions as a Panel were presented to, and unanimously agreed with by, the entire ERAB in August 1980. The major recommendation was:

> "1. *The magnetic fusion program can, and should, embark on the next logical phase toward its goal of achieving economic feasibility of magnetic fusion.* To this end a broad program of engineering experimentation and anslysis should be undertaken under the aegis of a Center for Fusion Engineering (CFE).
>
> "A key element of the program should be a device containing a burning plasma, and incorporating in its construction those technological features which can serve as a focus for the development of future reactor technology..."

This recommendation, and most of the other recommendations of the Panel, were incorporated promptly into the program planning of the Department.

Following the report of the Buchsbaum Panel, a number of complementary actions took place. A similar panel was established in the European Community and was chaired by the Vice President of Research and Development for Siemens Corp. Dr. Heinz Beckurts. After six months of review, it made a positive report on the European program recommending budgetary increases especially in engineering technology areas and looking to initiation of a device closely paralleling the ETF in objectives, following successful operation of the Joint European Tokamak (JET) at the Culham Laboratory in Great Britain.

In Japan, a Fusion Research Council review of its program recommended that Japan embark on a broad plan leading to an Engineering Test Reactor in the mid-1990's. This device would have considerably broader objectives than those recommended by the Buchsbaum Panel for the FED, including the production of some electricity. That plan has been accepted by the Japan Atomic Energy Commission and is now in process of being endorsed as a national policy. When Japan embarks on a course of this type as a national commitment, the probability of its carrying through to a conclusion is high.

In the United States, the Congress, acting on the basis of the ERAB Panel recommendations, enacted Public Law 96-386 on October 7, 1980. This Bill was approved in the House by a vote of 365-7 and by unanimous voice vote in the Senate. The findings and policy statement of that Act stated in part:

> "Sec.2.(a) The Congress hereby finds that--
>
> "...(2) the energy policy of the United States must be designed to ensure that energy technologies using essentially inexhaustible resources are commercially available at a time prior to serious depletion of conventional resources:
>
> "(3) fusion energy is one of the few known energy sources which are essentially inexhaustible, and thus constitutes a long-term energy option;...
>
> "(6) to ensure the timely commercialization of magnetic fusion energy systems, the United States must demonstrate at an early date the engineering feasibility of magnetic fusion energy systems...
>
> "Sec.2.(b) It is therefore declared to be the policy of the United States and the purpose of this Act to accelerate the national effort in research, development and demonstration activities related to magnetic fusion energy systems. Further, it is declared to be the policy of the United States and the purpose of this Act that the objectives of such program shall be --
>
> "...(2) to establish a national goal of demonstrating the engineering feasibility of magnetic fusion by the early 1990's.
>
> "(3) to achieve at the earliest practicable time, but not later than the year 1990, operation of a magnetic fusion engineering device based on the best available confinement concept;
>
> "(4) to establish as a national goal the operation of a magnetic fusion demonstratoin plant at the turn of the twenty-first century;...
>
> "...(7) to continue international cooperation in magnetic fusion research for the benefit of all nations.
>
> "(8) to promote greater public understanding of magnetic fusion;
>
> "(9) to maintain the United States as the world leader in magnetic fusion."

The Act and the ERAB recommendations are basically in consonance both as to the strategy and the schedule for carrying fusion forward; first to establish its technical feasibility as well as its scientific feasibility by the early 1990's, and then to demonstrate its commercial usefulness by the turn of the reviews, and an Act of Congress, the fusion program seemed to have arrived finally at a consensus strategy and timetable and a statement of national intent.

It is an irony of history that this planned broadening and acceleration of fusion research has now run directly into the perceived need to sharply reduce all non-defense spending. In the United States the expenditures for magnetic fusion have been reduced sharply from the levels required to carry out the program outlined by the Buchsbaum Panel and authorized by the Act of 1980. The proposed FY 1983 budget is 24 percent below the FY 1977 budget in real buying power, and all the initiatives designed to carry out the recommendations of the Panel are cancelled or postponed indefinitely. The completion of the Mirror Fusion Test Facility (MFTF-B), which was to have made possible an informed comparison between toroidal and linear confinement concepts by the mid-80's, has been postponed up to 3 years. The program is in imminent danger of being returned to a "science only" orientation. The Secretary of Energy has testified that his advisors tell him fusion is 30, 40 or even 50 years away, and that it should be science oriented with only a minimum of engineering effort.

During all but the last six weeks of the period during which the FY 1982 and FY 1983 budget actions were taking place, the decision-making positions in the Department of Energy, with the exception of the Secretary and Deputy Secretary, were filled with temporary appointments of career civil servants. The Examiner of the Office of Management and Budget while the FY 1983 budget was under development, was a temporary employee.

Now you will see where the two decisions referred to at the beginning have been made. The first was to forego, for an undetermined but extended period, the strategy and thrust of the ERAB Panel recommendations and the provisions of the Magnetic Fusion Energy Engineering Act of 1980. (The Act was characterized at senior levels in the Department as "permissive" and "a silly piece of paper".) The second was to delay the major facility in mirror system development (MFTF-B) by up to three years and, therefore, to forego an opportunity to make an informed judgment between toroidal and linear systems mid-decade as proposed by the DOE Policy Statement of 1978. Those two decisions leave the program without the strategic backbone of either the Foster or Buchsbaum review recommendations--a collection of individual projects and activities but without a mission or a timetable.

The plan to increase industry involvement in fusion development in a deliberate way will be postponed indefinitely, and the industrial and economic benefits of high technology development (spinoffs) which would have become increasingly important with an accelerated fusion engineering technology program, will be lost.

However, implicit in the FY 1982 and FY 1983 budget actions described above is an even more damaging intent--that of redirecting fusion research back to science objectives only and away from engineering technology developments looking to practical ends. The persons who have shaped this new policy have stated their purpose publicly and privately, and their actions support their words. The orientation toward making fusion practical and useful which began eight years ago is now being rescinded. Thus, what is happening goes well beyond budget policy or budget levels alone.

Why this sudden reversal in the national policy toward fusion? The obvious and immediate answer is that proceeding as planned required mortgages on the future at a time when the overriding Administration objective was to balance the budget. But the new Administation's policy statements as forwarded to the Congress by the President in the National Energy Plan included the following:

> ". There is an appropriate Federal role in certain long term research and development.
>
> ". The goal of long term R&D is to develop promising technological innovations to the point where private enterprise can reasonably assess their risks.
>
> ". The Federal Government recognizes a direct responsibility to demonstrate the scientific and engineering feasibility of fusion."
>
> (emphasis added)

Moreover, considering the historic implications of fusion and the potential for return on investment from the technological development activities, the incremental cost which would have required doubling the present budget from $400 million to about $800 million annually over a five-to-seven year period seems a reasonable investment notwithstanding other budget pressures. And these incremental costs can be compared with the trillion dollars expected to be invested in energy facilities during this decade, or the $60 billion annually exported for oil.

The Administration's recommendations for the other large programs in the Energy Research activities of the Department of Energy (High Energy Physics and Basic Energy Sciences) were exempted from the cuts which were made in the magnetic fusion budget. Therefore, I conclude that there were other factors than budget restrictions alone at work.

To some degree, supporters of fission energy, and particularly the breeder reactor, have worried that if fusion is worked on hopefully and aggressively there will be a reduction in enthusiasm and support with which fission and the breeder are pursued.

There is also a question in any energy development scenario as to eventual competition with all other energy options, including specifically fossil reserves. This seems especially shortsighted regarding fusion since in a very real sense, "it is not an option". The world will be different within fifty years in the case where fusion is developed as compared to the one if it is not. In that sense the development of fusion is a black and white issue.

But I believe the root cause of this abrupt turning back from a national commitment to carry on with U.S. leadership in fusion development is a failure to perceive, on the part of responsible officials in the Government and by the public generally, the total significance of energy to national security and economic strength and the extreme importance of developing and exploiting whatever potentials exist in any of the energy "options". As a result it is especially difficult to support any sort of intensity of effort on a program whose practical payoff is at least two decades in the future.

All of this would be more readily understandable if the magnetic fusion program were failing technically or organizationally, but these recent actions have taken place despite continued impressive technical advances throughout the program. In the last several years these have been of a kind which have not created publicly understandable headlines, but whose implications for achievement of practical fusion energy have been significant to a greater extent than during any similar period in the past. These advances represent valuable return on the investment which the United States has made since 1973.

Recent conceptual designs of fusion power reactors, taking advantage of the many advances already accomplished or now foreseen, provide increased confidence that one or more of the plasma confinement concepts can, in fact, be developed into useful, practical, economic power producers. In short, this has been a rich period of experimental and theoretical advances. Certainly, there has been no indication of major setbacks to the steady advances in magnetic fusion over the last decade.

Let me now make what I think to be a vital point in this matter. Fusion is a difficult undertaking--probably the most lengthy and difficult technical development ever undertaken as a single organized, non-military development activity. It is vitally important, therefore, to have a strategic framework and schedule on which to make internal program decisions and judge progress. But fusion has no precedent as a research and development program, not only because it is so long term, but also because it is different in kind from its large predecessors, such as fission energy or space exploration. Therefore, and because of the long time constants associated with developments of this kind (at least ten years minimum for each major step), it seems vital to determine at the earliest practicable date whether fusion can be counted on as a part of long range energy policy. Obtaining an answer to that question may be more important if the answer is negative than if it is positive. Those working in the fusion field are increasingly confident the answer will be positive, but in either case, it seem vital to have an informed answer.

For these reasons, the Department proposed, and the Congress endorsed as the major near term program goal, the confirmation of both the scientific and technical feasibility of fusion by the early 1990's.

The fusion community worldwide is almost unanimous in concluding that scientific feasibility is assured and will be confirmed during the next five years in the Tokamak Fusion Test Reactor at Princeton, in the Joint European Torus in Great Britain, in the JT-60 in Japan, and in T-15 in the Soviet Union. What will not be done unless further steps are taken is sufficient engineering insights in plasma physics which inevitably will be obtained over the next decade in experimental devices now in operation or already under construction, an informed assessment of fusion's potential. That additional effort is what the ERAB Panel recommended and the Magnetic Fusion Energy Engineering Act translated into law.

It is difficult to understand why responsible officials of this Government would want to turn away from a highly successful program plan looking toward making fusion useful. It is especially difficult in view of the retreat from fission energy as seen in the reduction in new nuclear plant commitments by utilities. And it is especially difficult in view of recent hard evidence of the two threatening problems of fossil fuels--acid rain and climatic changes due to CO_2 in the atmosphere.

In any case, $444 million is a great deal to spend for purely scientific investigations of plasma physics without a practical mission objective. At the FY 1983 budget level of $444 million, progress will be made, new scientific results will be obtained and budgets in the fusion laboratories will be relatively comfortable. But the vital programmatic sense of the parts of a major development program fitting and working together towards a common goal will be lost. The program will be vulnerable to errors in judgment and further restrictions on its resources because it has no strong strategic logic from which to make decisions or justify support.

However, in an important sense, the first question is not budget levels but intent and commitment. Plans, strategies, schedules, attempts to establish goals and milestones for fusion have been made almost entirely from within the program. The first assistance from outside in this regard came from the Foster Committee Report which led to the Policy Statement on Fusion in 1978. Further progress in the program then led to the Buchsbaum Report and the Magnetic Fusion Energy Engineering Act of 1980. Finally, with that Act, there was an official policy stated strongly from outside the program--one which made good sense from the standpoint of the technical complexity of fusion and its historical implications, and one which, it seemed to many, was fiscally responsible--i.e., total expenditure estimated to be required was spread over two decades and was never as much as present and continuing budgets for fission development or space.

What is still missing is a national intent, an expressed purpose within the mechanisms of Government that this Nation should, as an investment in its future security and econommic health, proceed in a deliberate, persistent and technically honest way to make fusion energy available in a practical sense. A restatement of such an intent is more important in the first instance than increased budgets, because such an intent, properly expressed, contributes greatly to more effective use of whatever resources are supplied.

What are the programmatic effects of this decision not to proceed deliberately and hopefully with fusion development?

1) The date on which fusion can be counted on to mitigate the many and increasingly intractable problems of energy will be postponed at least year-for-year.

2) A consensus strategy based on high level review and Congressional support will be lost. It is not likely a similar consensus on a new strategy can be established in a short time. In other words, this is not simply a matter of increasing following year budgets "when the economy recovers".

3) U.S. world leadership in fusion and the ability of the U.S. to work effectively within cooperative arrangements to strengthen world programs as a whole will be weakened.

4) The potential of developments on the technology side of fusion which were pushing the state-of-the-art in a number of technological areas, and thus to inspire U.S. industrial innovations, will be lost. This is especially true since the majority of the engineering technology program would have been carried out in industry.

Thus, within less than a year, without internal or external programmatic review of any consequence, and on the basis of judgments of individuals with no previous experience or commitment to fusion, the consensus judgments of the Congress and three high level scientific reviews, as well as of the professionals in the fusion program who have put their reputations and careers on the line--all have been overridden.

If, indeed, it is considered that fusion is "30, 40 or 50 years away", and if the program is to be essentially a pure science program without practical goals and milestones, without a mission and without a strategy on which to base base decisions and measure progress, then the present budget of $444.1 million is sufficient. If on the other hand, the Congress is willing to maintain the fusion program at a steady level; i.e., provide for 10% inflation between the FY 1982 and FY 1983 budgets, then the whole thrust of the mission orientation intended by the Congressional Act could be maintained, albeit at a slower pace. That would require adding $56 million to the $444 million FY 1983 budget request (i.e., $44 million above the $456 million FY 82 budget) as follows: $10 million to establish a Center for Fusion Engineering and commence serious conceptual design of a Fusion Engineering Device; $15 million to commence construction of the Fusion Materials Irradiation Test, the only machine planned anywhere in the world which would create a neutron environment similar to that of a fusion reactor; $21 million to make a reasonable beginning on the Elmo Bumpy Torus Proof-of-Principle experiment, the first project for which industry will have system responsiblity under McDonnell Douglas; and $10 million with $5 million more from other sources within the program to put the Mirror Fusion Test Facility back on its original schedule of completion in 1985.

It is an irony of history--in my view a tragic one--that the United States finds itself, having arrived at recognized world leadership in an important technology with great implications both for this nation and the rest of the world, unable to find the resources--both organizational and financial--to carry through with previously characteristic American will and vitality the program which had been carefully laid out over the last four years.

As I watched, from my position as program director, the events affecting the program over the last five years, I often asked myself whether the program could be carried to a successful conclusion in the present social and political climate which emphasizes shorter term payoffs and goals. After the events of this past year, I have concluded, reluctantly, that there is grave doubt that fusion can be carried out as an intelligently organized, mission-oriented program, unless, perhaps, if driven by crisis. Because of the inherent time constraints, that may be too late!

Sidney Harris has said,

> "An idealist believes the short run doesn't count. A cynic believes the long run doesn't matter. A realist believes that what is done or left undone in the short run determines the long run."

It may be that this administration cannot afford to carry out, in a deliberate hopeful way, the consensus plans laid out for fusion development; but no one should assume that not doing so will be without lasting consequences. The future will appear different within 10 years, and it will be different within 25.

BIOGRAPHY

EDWIN E. KINTNER

Edwin E. Kintner was Associate Director for Fusion Energy, within the Office of Energy Research, U.S. Department of Energy (DOE) until January 9, 1982. Prior to September 1979, he served in this capacity within DOE's Office of Energy Technology, having assumed the post upon the creation of the Department in October 1977.

Mr. Kintner served in a similar position within the Division of Magnetic Fusion, U.S. Energy Research and Development Administration (ERDA), from April 1976 until the merger of ERDA with DOE. From January 1975 until April 1976, he served as Deputy Director of the Division.

Prior to service with ERDA, Mr. Kintner was assigned to the former Atomic Energy Commission (AEC). He joined the AEC in 1965, serving simultaneously as Assistant Director for Reactor Engineering and Deputy Director of Reactor Research and Development. In January 1975, and the absorption of fusion research functions by the newly-established ERDA, he transferred to that agency.

From 1963 to 1965, Mr. Kintner was President and General Manager of South Portland Engineering Company, South Portland, Maine, where he was engaged in the manufacture of large components for submarines and in building medium-sized ships.

Mr. Kintner served with the U.S. Navy from 1941 until he retired in 1963. Of his 22 years of service with the Navy, 14 years were devoted to assignments within the Naval Reactors Program. During this period, he served as Projects Officer for the USS Nautilus Project; Head, Advanced Design Group, Naval Reactors Branch; first Nuclear Power Superintendent, Mare Island Naval Shipyard; and Assistant Manager for Operations at the Pittsburgh Naval Reactors office. He was awarded the Navy Commendation Medal for his contribution to the Naval Nuclear Propulsion Program from 1950 to 1963.

Mr. Kintner graduated from the U.S. Naval Academy in 1942. He received an M.S. degree in naval construction and marine engineering in 1946 and an M.S. degree in nuclear physics in 1950. Both advanced degrees were awarded by the Massachusetts Institute of Technology.

Mr. YOUNG. Thank you very much, Mr. Kintner.

Dr. Dean?

STATEMENT OF DR. STEPHEN O. DEAN, PRESIDENT, FUSION POWER ASSOCIATES

Dr. DEAN. Thank you. It is a pleasure to be back.

I resigned from the Department of Energy 3 years ago, although it did not attract the same amount of public attention as Ed Kintner's did. I was working for Ed at the time. I left the Department to form Fusion Power Associates because I recognized that unless we started to mobilize the industry and the private sector, we were not going to take this program from a scientific research mode to something that would develop practical products.

Two individuals joined me to form the initial board of directors to incorporate Fusion Power Associates. In addition to myself there was Dr. Alvin Trivelpiece who testified yesterday and who is now the Director of Research at the Department of Energy and Dr. Nicholas Krall, who is the vice president of Jaycor and who is now the chairman of our board.

We started 3 years ago with 10 corporate members; today we have 30 corporate members and 20 affiliates and, I believe, we are making effective progress in mobilizing the industry and the private sector in bringing to bear the kind of perspective that is needed in the fusion program.

I would like to enter my prepared remarks into the record and make a few summary comments.

Mr. YOUNG. Without objection, so ordered.

Ed Kintner and Mike McCormack have both mentioned this question of scientific research versus engineering development. I would like to just comment that while it is very important to try to understand all the different physics' constraints and all the kinds of problems and solutions that the physicists are inventing and solving every day, it is also very important to keep our eye on the fact that we are developing this program in order to benefit society and not just to publish papers in scientific journals.

[Slide 1 shown.]

ENERGY FROM FUSION WILL BENEFIT SOCIETY

BY:

- PRODUCTION OF ELECTRICITY
- PRODUCTION OF HYDROGEN FOR SYNTHETIC FUELS AND TRANSPORTATION
- PRODUCTION OF FISSILE MATERIAL FOR FISSION REACTORS AND DEFENSE
- INDUSTRIAL PROCESS APPLICATIONS
- SPACE VEHICLE PROPULSION

FUSION USE WOULD HELP TO RELIEVE ONE OF THE PRIMARY CAUSES OF WORLD TENSION--THE UNEVEN DISTRIBUTION OF PRIMARY FUEL RESOURCES.

A FUSION ECONOMY WOULD PROVIDE A STABLE ENERGY BASE FOR SUSTAINED WORLD ECONOMIC GROWTH.

SLIDE 1

Fusion is one of the unique forms of energy in the sense that, not only can it be used to make electricity, but it probably is the only source that has so many different potentially useful applications. Other energy sources have unique potential for one or the other of these applications but fusion is probably the only one that has the potential, in fact, to do all of the various things that are listed. In addition, the use of fusion would help to relieve one of the primary sources of world tension—uneven distribution of primary fuel resources, because the fuel for fusion, as you know, comes from water.

[Slide 2 shown.]

FUSION ENERGY SHOULD BE ENVIRONMENTALLY AND SOCIALLY ACCEPTABLE

SINCE:

- THERE ARE NO COMBUSTION PRODUCT WASTES
- RADIOACTIVITY INDUCED BY NEUTRONS IN STRUCTURAL MATERIALS IS IN A MORE BENIGN FORM THAN IN FISSION REACTORS
- THERE IS NO POSSIBILITY OF RUNAWAY NUCLEAR REACTIONS
- THE HAZARDS ASSOCIATED WITH POSTULATED ACCIDENTS ARE THOUSANDS OF TIMES SMALLER THAN FROM FISSION REACTORS
- THE MINING, MILLING AND TRANSPORTATION OF MATERIALS REQUIREMENTS ARE SMALLER THAN FOR OTHER ENERGY SOURCES
- THERE ARE NO REQUIREMENTS FOR TRANSPORTATION, REPROCESSING OR LONG-TERM OFF-SITE STORAGE OF RADIOACTIVE SPENT FUEL

SLIDE 2

Also keep in mind that we are developing fusion for environmental reasons and social reasons also. There are a variety of features of fusion that make it different qualitatively from other energy sources and that will make the world a better place to live in if fusion is developed. I might mention the fact that fusion is such an intense energy source in terms of its utilization of the fuel that, for example, a 1,000 megawatt electric powerplant can run for a whole year on only one small pickup truck load of fuel and contrast that to a similar-sized coal plant that requires 191 trains of 110 cars each to deliver the coal and a like number to remove the ash.

I would like to comment on this question of the way of looking at the program as a research program or as a development program. The fusion program consists of a variety of scientific approaches all of which require proof of principle experiments at one level or another and it is supported by a variety of research and a variety of engineering development.

In the past several years we have initiated the construction of two machines of very large size: the Tokamak Fusion Test Reactor [TFTR], and the Mirror Fusion Test Facility [MFTF]. Those two machines together cost about a half a billion dollars. They are $200 to $300 million each. In the process of building those machines, we have already moved into the engineering phase of fusion development. We are developing engineering in order to build these machines.

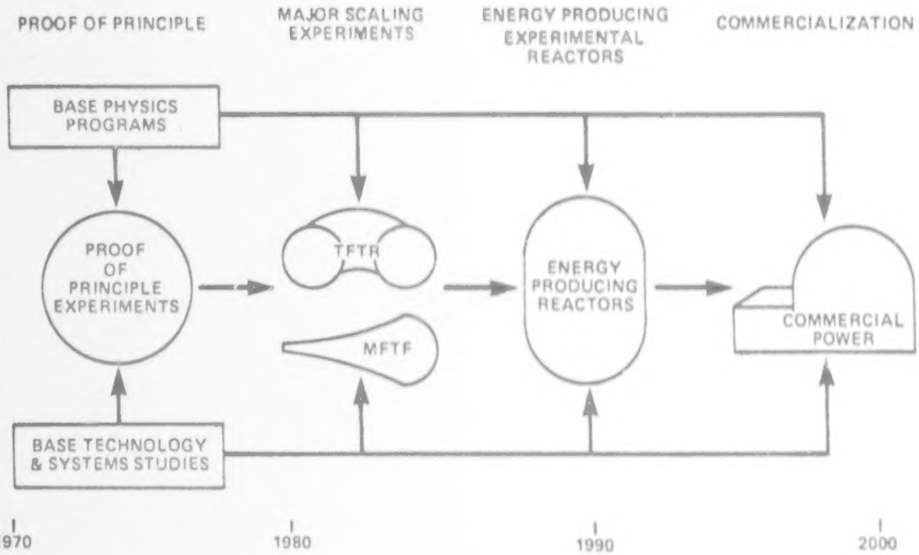
In addition to those machines, we are developing engineering on items like the Large Coil Project at Oak Ridge and the Tritium Systems Test Assembly at Los Alamos. So the fusion program has already got a heavy component of engineering in it. What we are in is a transition from a program which was dominated by scientific research to a program which has to move, in the 1990's, to actually build reactors that make a lot of fusion power.

This is the question: How fast are we going to develop the engineering and make the commitment to actually be building prototype fusion power reactors that make copious amounts of fusion power? In that context, I would like to put in a very strong plug to this committee to keep the MFTF project on schedule. That machine is costing you $200 million. If you delay that program by 2 or 3 years, you are going to pay about $100 million of increased costs before you get it finished.

I would like to comment that although the TFTR is a very important project and it is the lead program in the tokamak program, it does not have superconducting magnets; it is not a steady-state device such as eventual fusion reactors very likely will have to be. The MFTF, on the other hand, has superconducting magnets, it is a steady-state type of experiment and that kind of technology is very important to the tokamak program and the overall flow of fusion development. It is needed on a reasonable time scale in order that decisions can be made to build the right type of energy producing reactors in the nineties.

[Slide 3 shown.]

STAGES IN FUSION ENERGY DEVELOPMENT


PROOF OF PRINCIPLE
MAJOR SCALING EXPERIMENTS
ENERGY PRODUCING EXPERIMENTAL REACTORS
COMMERCIALIZATION
BASE PHYSICS PROGRAMS
PROOF OF PRINCIPLE EXPERIMENTS
TFTR
MFTF
ENERGY PRODUCING REACTORS
COMMERCIAL POWER
BASE TECHNOLOGY & SYSTEMS STUDIES
1970
1980
1990
2000

SLIDE 3

This slide was made a few years ago. Since that time the Elmo Bumpy Torus has come on the scene and I remind you that whereas it is called a "proof of principle" experiment, its price tag is $100 million. It is a steady-state machine and it also has superconducting magnets. It is an engineering machine as well as a physics machine and its impact on the fusion program is only second in importance to the MFTF and the TFTR. The EBT-P project should also be constructed expeditiously. We have already made commitments: We have picked a site; we have picked a contractor and we ought to get on with the job.

I would like to comment about the Department of Energy and how it manages this program. Looking around at the pictures on this wall, as Mike McCormack mentioned, I am a little bit moved to note the contrast in the way that NASA managed that program as to the way the Department of Energy conceives of managing this program.

It is not true that the space program did not have scientific uncertainties in it; there were a lot of scientific uncertainties about whether man could survive in space and there were a lot of scientific experiments conducted in satellites and elsewhere and are still being conducted about how we move into space, as well as a big engineering development program.

The Department of Energy seems to look at the fusion program as research—a program that should be managed in a kind of "research mode." It looks at proposals from the scientific community, it reviews them in the peer review process, it does the best it can to meet its milestones and so on; the DOE does not seem to have a concept of how to run this program as a development program with a systems management approach to it.

I think two things happened during this last year, that you are well aware of with regard to the Fusion Act, that point out the problem of management at the Department with respect to this program.

The first is that the act required that they prepare a plan for you on how to establish a Center for Fusion Engineering and they were supposed to tell you that last summer. As you know, they told you that they were not going to do it. They were also told by the act that they should give you a comprehensive program management plan a couple of months ago and they told you that they could not do that either. Now, neither of those actions' required by the act, would have required hardly any money at all for them to do and yet in neither case did they choose to comply and, as far as I know, on the Center for Fusion Engineering they still do not plan to establish it. There is a line item in the fiscal year 1982 budget of $9.5 million, in this year's budget, that is labeled, "Center for Fusion Engineering." None of that money is being spent on a Center for Fusion Engineering; it is all being spent on various engineering projects of various sorts and conceptual designs, but it is not being used to establish a Center for Fusion Engineering.

With respect to the comprehensive management plan that you asked for, I understand from testimony yesterday that they will now start to prepare it for you. As they start to do this I would urge you to keep your eye on whether or not they are providing you a real management plan because their tendency will be to provide you with program descriptions and program analyses and program milestones, and not deal with management issues.

One has to really force this issue, it seems to me, about how this program is going to be managed. It requires a systems management approach. One of the reasons they are not going to establish a Center for Fusion Engineering is because they conceive it as another national laboratory and we have got so many national laboratories now, why do we need another one? If you conceive of the Center for Fusion Engineering as another national laboratory, I agree that we do not need another one; we have got plenty and we could just convert one. The Center for Fusion Engineering needs to be a dynamic systems management organization; a lean organization that does the things that Ken Matson described to you in his testimony earlier. That is the kind of organization it should be. It does not cost a lot of money but it does bring discipline and an engineering approach to developing a program that will lead to a practical product and that, I think, is the big distinction between what we are saying to you today about engineering and management and development as opposed to scientific research.

I am not opposed to scientific research; I do not think any of us are opposed to scientific research. The best minds in this program are the scientists and the program totally depends on their inventions in order to be successful. Nobody is talking about cutting them off at the knees or cutting off the new concepts that are coming up. But this program has got to start thinking like a successful development program, the way the Apollo program thought of itself. They were going to do it in a specific time, they were going to bring in the contractors to do the job and get on with it in a certain manner. That is what has to come to bear on this program that it does not now have.

Although the Magnetic Fusion Engineering Act and this committee deal only with magnetic fusion, I would like to divert slightly at the moment to comment that the Department of Energy also sponsors a program in inertial confinement fusion that is managed by the military. I would urge this committee to influence your colleagues in the Armed Services Committee to spend some fraction of whatever budget they come up with on the civilian applications of that technology. It would be a tragedy if that technology gets developed only for military purposes and by some oversight of who is responsible for it they stop looking at what the civilian reactors might look like or what the civilian applications could be. It is a relatively small amount of additional money that is required for that and I would urge you to take an interest in it.

[Slide 4 shown.]

INDUSTRY HAS THE SKILLS TO DEVELOP FUSION
AS A PRACTICAL ENERGY SOURCE

EXAMPLES INCLUDE:

SYSTEMS DESIGN, ANALYSIS AND MANAGEMENT

BDM CORP., BECHTEL GROUP, BOEING ENGINEERING AND CONSTRUCTION CO., BURNS AND ROE, INC., EBASCO SERVICES, EDS NUCLEAR, INC., KAMAN NUCLEAR, INC., GILBERT COMMONWEALTH ENGINEERS AND CONSULTANTS, JAYCOR, W. J. SCHAFER ASSOCIATES, INC., SCIENCE APPLICATIONS, INC., STONE AND WEBSTER ENGINEERING CORP., AND TRW

FACILITY CONSTRUCTION, COMPONENT DEVELOPMENT AND MANUFACTURE

AYDIN ENERGY DIVISION, COMBUSTION ENGINEERING, GENERAL DYNAMICS, HIPOTRONICS, ILC TECHNOLOGY, MAXWELL LABORATORIES, MCDONNELL DOUGLAS ASTRONAUTICS CO., THERMO-ELECTRON CORP., UNITED ENGINEERS AND CONSTRUCTORS, UNIVERSAL VOLTRONICS, AND WESTINGHOUSE

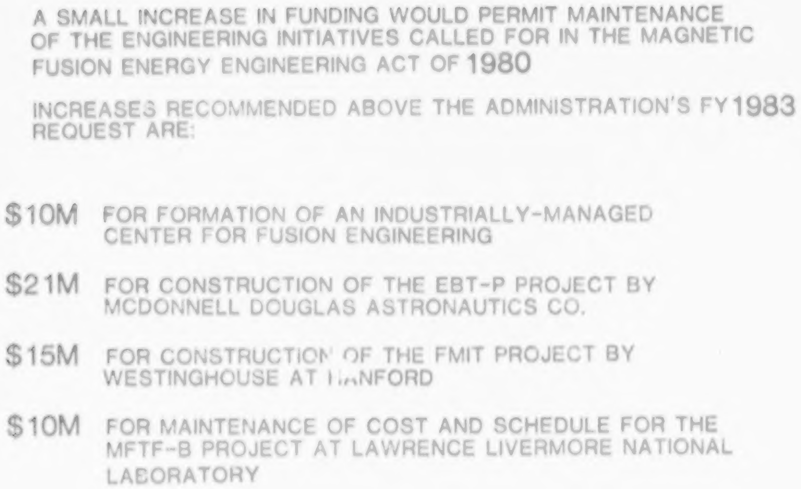
FUSION FACILITY OPERATIONS

FUSION ENERGY CORP., GENERAL ATOMIC CO., KMS FUSION, INC., AND MATHEMATICAL SCIENCES NORTHWEST, INC.

SLIDE 4

Just to give you some examples which I have taken from my own membership, the industry is out there and ready to do this job. You notice the kind of skills I think they can bring to bear on this problem: systems design analysis and management; facility construction; component development and manufacture; fusion facility operations. These are not research topics. We are not trying to get the industry in here to usurp the scientific roles of the laboratories and the universities. These are the kinds of skills that, in fact, the industry excels in and the laboratories and universities do not excel in. This is a complementary function that needs to be brought into this program.

[Slide 5 shown.]



A SMALL INCREASE IN FUNDING WOULD PERMIT MAINTENANCE OF THE ENGINEERING INITIATIVES CALLED FOR IN THE MAGNETIC FUSION ENERGY ENGINEERING ACT OF 1980

INCREASES RECOMMENDED ABOVE THE ADMINISTRATION'S FY 1983 REQUEST ARE:

$10M	FOR FORMATION OF AN INDUSTRIALLY-MANAGED CENTER FOR FUSION ENGINEERING
$21M	FOR CONSTRUCTION OF THE EBT-P PROJECT BY MCDONNELL DOUGLAS ASTRONAUTICS CO.
$15M	FOR CONSTRUCTION OF THE FMIT PROJECT BY WESTINGHOUSE AT HANFORD
$10M	FOR MAINTENANCE OF COST AND SCHEDULE FOR THE MFTF-B PROJECT AT LAWRENCE LIVERMORE NATIONAL LABORATORY

SLIDE 5

Finally, I would like to make recommendations on additions to the budget. They are the identical recommendations that Ed Kintner and Mike McCormack made: That is not an accident. Mike and Ed and I put our heads together several weeks ago to ask: What could we really come up with that would be helpful to this committee? If this committee, in fact, were able to come up with these dollars, we could at least attempt to keep this program on track even though not on the schedule envisaged in the Fusion Act.

There are these four items:

Ten million dollars for the formation of an industrially-managed Center for Fusion Engineering. There is no advocate out there for it. There is no laboratory going to come in here and lobby for it. The industry is not sure who should lobby for it because there is no competitive process going on and no contractor has been selected. But that is a very important recommendation in this budget.

I mentioned earlier the EBT project: It has been started. It should be finished.

The FMIT project, which Mike McCormack mentioned and which Dominic Repici indicated to you is important even to the private sector programs should be completed, and the MFTF project, I think probably the most important of all, you have got to keep that machine on schedule or you are going to pay a very big price tag financially on it and you are also going to hurt the chances that we will be able to make a clear decision on our first energy-producing reactors between tokamaks and mirrors.

Thank you.

Mr. YOUNG. Thank you very much, Dr. Dean for your fine testimony.

[The prepared testimony of Dr. Dean follows:]

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STATEMENT OF
DR. STEPHEN O. DEAN
PRESIDENT
FUSION POWER ASSOCIATES
TO THE
SUBCOMMITTEE ON ENERGY RESEARCH AND PRODUCTION
OF THE
HOUSE COMMITTEE ON SCIENCE AND TECHNOLOGY
MARCH 24, 1982

Fusion Benefits to Society

The astounding changes in living standards of the twentieth century are directly traceable to advances in technology. There is no evidence that the rate of technological innovation has slowed; in fact technological change is impacting our lives at an ever increasing rate. Looking to the future, history cautions us not to be too presumptuous of our ability to predict it. Who, for example, would have predicted 50 years ago the widespread use of microprocessors and a growing market in personal computers?

A common denominator which underlies modern society is the availability and affordability of energy. Here, many would have us believe that the world is soon to run out of it. Others believe energy is abundantly available and the whole problem is one of economics. Still others believe the energy problem is primarily one of who owns the most easily used resources. The truth is, of course, that all these views are partly correct but not complete and that the true energy problem is a complex one which defies a unique "solution". Predictions of future demand and use patterns, let alone economics, is a fiction of the professional energy analyst. Systematic analysis is worthwhile; but we should not claim any great precision for the resulting forecasts.

Many sources of energy are in use today: fossil (coal, oil, gas, wood), nuclear fission solar, etc. Each has advantages which result in its use for many applications. Each has its list of difficulties. Coal, for example, is difficult to mine, transport and burn in a safe and environmentally acceptable manner. Many nations of the world have no coal. Oil is now largely controlled by a cartel which has the power to set prices and availability in a way which could destroy economies and be the source of world war. Nuclear fission deployment has spawned unprecedented social resistance and has been regulated to the point where the costs of construction are primarily tied to licensing delays. And so on Still, each of these sources of energy is playing an important role in today's world. Technological advance does not stand still, however, and we can already begin to see that a new energy source, fusion will emerge early in the twenty-first century.

"TO TAKE FROM THE SEA AND TO IMITATE THE SUN"

Fusion is the energy source of the Sun and stars It is the combination of hydrogen at high temperature to form helium. Fusion is the opposite of fission, the process in which heavy atoms (uranium, plutonium) are split, releasing energy. For a given weight of fuel, the energy released by fusion exceeds the energy released by fission and far exceeds (by millions of times) the energy released in any chemical reaction (e.g., the burning of coal or oil). Practical amounts of fusion energy will be produced in a fusion power plant.

Fusion takes its primary fuel, deuterium, from the sea and the reaction is so energy efficient that a 1000 MWe power plant can run for a whole year on only one pickup truck load of fuel. Contrast this with a coal plant of the same size which would require 191 trains of 110 cars each to deliver the coal and a similar number to haul away the ash.

Energy from fusion may be used in many ways to benefit society. For example, fusion may be used to:

- o Make electricity.
  - Studies show that the cost of electricity should be roughly comparable to that from other energy sources in the next century. Abundant electricity generated from non-polluting sources would have a major impact on future society, e.g., through the widespread use of electric vehicles.

- o Produce hydrogen.
  - Hydrogen may be burned with oxygen (to form water vapor) and used, for example, as a fuel for transportation. It is also an essential ingredient in most synthetic fuel processes.

- o Make fissile material.
  - The neutrons from fusion reactions are efficient producers of fissile material for use in nuclear fission applications. For example, a fusion reactor could produce enough nuclear fuel to supply up to 20 fission reactors of equal capacity.

Other uses of fusion energy include most industrial processes and potentially new chemical and metallurgical processes. In the long-term, fusion may be used as a source of energy for propulsion of space vehicles. It has by far the highest specific impulse of any propellant and is the only known potentially practical way to reach speeds which are required for exploration beyond the solar system.

Environmental Characteristics

As world population and energy consumption inevitably increase, environmental damage (some potentially irreversible) becomes of growing concern. Most of the current resistance to the widespread use of coal and nuclear fission stems from fears of permanent damage to our environment, health or safety. Less widely known is the massive mining of materials which would be required should solar energy systems, as now conceived, be deployed as a baseload energy source for society. Fusion energy should be environmentally and socially acceptable because:

- o There are no combustion wastes.
  - The product of the fusion reaction is helium--a non-toxic, non-radioactive, valuable gas.

- Radioactivity induced by neutrons in structural materials is in a more benign form than in fission reactors.
  - Calculations indicate that the biological hazard potential from postulated accidents is hundreds to hundreds of thousands of times less than similar postulated accidents in fission reactors.

- There is no possibility of a runaway nuclear reaction.
  - The fusion process is difficult to initiate and sustain. Any malfunction immediately quenches the reaction.

The mining, milling and transportation requirements for materials are smaller for fusion plants than for other energy sources and there is no requirement for transportation, reprocessing or long-term off-site storage of spent fuel.

Readiness for Engineering Development

The Magnetic Fusion Energy Engineering Act of 1980 sets forth clear goals and timetables for fusion development. Several prestigious review panels have certified the readiness of the fusion program to move into engineering development and their recommendations were incorporated into the fusion Act.

Rapid progress in fusion energy development has occurred in recent years. Success, from a scientific viewpoint, is now assured. Although there remain many difficult engineering problems to be overcome, all have potential technical solutions.

Industry has played an increasing role in fusion development. Today there are many industries with proven skills to contribute, indeed to provide leadership, to the engineering development phase of fusion. Key areas of industrial expertise include (1) systems design, analysis and management (2) facility construction, component development and manufacture and (3) fusion facility operations. Examples of companies which have experience in these areas are shown below.

Systems Design, Analysis and Management

BDM Corp., Bechtel Group, Boeing Engineering and Construction Co., Burns and Roe, Inc., Ebasco Services, EDS Nuclear, Inc., Exxon Nuclear, Inc., Gilbert Commonwealth Engineers and Consultants, JAYCOR, W. J. Schafer Associates, Inc., Science Applications, Inc., Stone and Webster Engineering Corp., and TRW

Facility Construction, Component Development and Manufacture

Aydin Energy Division, Combustion Engineering, General Dynamics, Hipotronics, ILC Technology, Maxwell Laboratories, McDonnell Douglas Astronautics Co., Thermo-Electron Corp., United Engineers and Constructors, Universal Voltronics, and Westinghouse

Fusion Facility Operations

Fusion Energy Corp., General Atomic Co., KMS Fusion, Inc., and Mathematical Sciences Northwest, Inc.

DOE and the Fusion Act

Two specific events of the past year suggest that DOE has been lax in complying with the fusion Act. First, in a July 7, 1981, letter from Secretary Edwards to Congressman Fuqua, Edwards states "We have determined that it is premature to establish fully the national Magnetic Fusion Engineering Center (CFE) at this time." In response (July 30, 1981) Mr. Fuqua said, "I would ask that you reconsider your present intention...and instead move forward within your FY 1982 budget, with formally soliciting proposals from all interested parties on establishing a CFE management scheme and operating team." The DOE has not responded further, and there is no evidence that they intend to take any action on the CFE. A second example is a January 29, 1982, letter of Secretary Edwards to Congressman Fuqua explaining why DOE has found it "impossible to prepare a Comprehensive Program Management Plan (CPMP) for Fusion by January 1, 1982" (as required by the Law). Edwards says this "impossibility" was due to "the uncertainty which has accompanied development of the budgets for Fiscal Years 1982-1983 and the fact that these budgets do not support the pace of the program development envisioned in the Act." Mr. Fuqua responded (February 23, 1982) saying, "The language of the Act and the intent of Congress with regard to the CPMP are clear. It does not seem to me that the fact that the Fiscal Year 1982 budget request for the magnetic fusion energy program was below the level envisioned in the Act and the subsequent uncertainty in the final appropriation process can serve as a basis for ignoring the requirements for preparation and transmittal of a Comprehensive Program Management Plan."

Recommendations

I recommend that the Congress reiterate to the DOE its expectation that DOE implement the engineering initiatives contained in the fusion Act, including the shifting of appropriate responsibility to industry.

A small increase in funding would permit maintenance of the engineering initiatives called for in the fusion Act. The increases which I recommend be added, above the Administration's FY 1983 request, are:

- $10M for formation of an industrially-managed Center for Fusion Engineering
- $21M for construction of the EBT-P Project by McDonnell Douglas Astronautics Co.
- $15M for construction of the FMIT Project by Westinghouse at Hanford
- $10M for maintenance of cost and schedule for the MFTF-B Project at Lawrence Livermore National Laboratory

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BIOGRAPHY

STEPHEN O. DEAN

PRESIDENT AND CHIEF EXECUTIVE OFFICER

FUSION POWER ASSOCIATES

Stephen O. Dean is president and chief executive officer of Fusion Power Associates, a non-profit association formed to pursue the development and utilization of fusion as an environmentally attractive energy option.

Prior to forming Fusion Power Associates in 1979, Dr. Dean was, from 1972 to 1979, Director of the Magnetic Confinement Systems Division of the Office of Fusion Energy at the U.S. Department of Energy and its predecessor agencies, the Energy Research and Development Administration and the U.S. Atomic Energy Commission.

From 1968 to 1972, Dr. Dean worked as a research physicist at the U.S. Naval Research Laboratory, where he performed experiments which were among the earliest in the field of laser fusion.

Born in Niagara Falls, New York on May 12, 1936, Dr. Dean earned a B.S. degree in Physics from Boston College, a Master of Science degree in nuclear engineering from the Massachusetts Institute of Technology and a Ph.D. in physics from the University of Maryland.

"TO TAKE FROM THE SEA AND TO IMITATE THE SUN"

Mr. YOUNG. Mike and Ed, can you tell us your understanding of where the FMIT project stands today? How many more dollars do we need to complete the effort and when can we expect to start getting data out of the device?

Mr. MCCORMACK. Mr. Chairman, I will submit for the record the total number of dollars required to complete the FMIT. We have recommended $14 million this year. The status of the program is that excavation is completed, and that, at Los Alamos work on the accelerator is essentially complete. Facility design has been completed, and a construction bid package could be offered any time. In short, if the Department of Energy would do now what the Congress said last year it should do now, a bid package for construction could be offered at once; and the plant could be on the line by 1985 or 1986.

Mr. Chairman, it should be emphasized that the FMIT is absolutely essential to every fusion project in the free world. The European Economic Community and the Japanese Government have, in reliance on the actions of this Congress and previous administrations, refrained from building such a machine themselves. It is utterly unrealistic to contemplate building of the fusion engineering devices being contemplated in our Federal program or overseas without first studying the characteristics of candidate metals for the first wall, and so forth. This can only be accomplished using the FMIT. The entire free world is dependent upon and waiting for the FMIT.

Mr. YOUNG. Mr. Kintner, do you want to address that? How many more dollars do we need if you have that information?

Mr. KINTNER. The total estimated costs for the project was $105 million on its previous schedule. What it would be now, I am not prepared to say.

I would like to add that I think if you took one individual project—lay aside the question of time and priority—but one individual project that is vital to fusion worldwide it is FMIT.

Mr. YOUNG. Dr. Dean, you talked about a system management organization and systems management approach. Could you elaborate a bit more on how this might be done?

Dr. DEAN. Yes, the situation is very analogous to the way, for example, that NASA managed the Apollo project or the Defense Department manages a major weapon systems development.

A fusion device and reactor is a very complicated object, it has many different subsystems: magnet subsystems, vacuum subsystems, power conversion equipment subsystems, materials, and so on. The skills to develop these various subsystems reside in different places. Somebody has to pull all of that act together in a way that minimizes the cost and schedule of the overall program. You can put contracts out with the various people to do development in these various areas, but if you do not have somebody who sees what is needed and when, so that the whole program fits together in some way that minimizes cost and schedule, then you will take a very long time and you will waste a lot of money. The systems approach is to look at the total problem, break it down into its subelement pieces and then find the people to do those things that are needed. Then, when a budget cut comes, you look at the schedule and you say, "OK, if this one slips a little bit, it is not so critical, but if that one does, it is critical." Then you adjust all of your program budgets and distribution in terms of an impact on the total flow of the total program as a system. This kind of approach is what is needed to be laid out in the comprehensive program management plan you have asked the DOE for. But it has not only to be laid out, the program has to be managed in a way to implement the decisions that way on a regular basis.

Mr. YOUNG. Thank you, Dr. Dean.

Mr. Kintner, on page 9 of your testimony, you say that:

> Fusion has no precedent as a research and development program if you say that not only because it is so long term, but also because it is different in kind from its large predecessors, such as fission energy or space exploration.

How is fusion different in kind from fission energy or space exploration?

Mr. KINTNER. Well, first, the important difference has to do with the fact that these other major development programs were, fundamentally, military—had military objectives, and that makes it much more difficult to obtain the persistent support needed to carry through a program like fusion.

I believe also that, taken as a whole, the variety of technological advances that must be made for fusion to be successful is broader than it was in space or than it was in fission, at least if one includes the original development of fission as simply for weapons.

It will take several decades, and that requires a kind of persistence and determination over a longer period of time than either of these other two programs have required. That is what I meant when I said it is "different in kind."

Mr. YOUNG. Very good.

Dr. Dean, do you agree that the first commercial application of fusion energy may well be the fusion-fission hybrid? Do you think the Department of Energy's program is addressing this technology in sufficient detail?

Dr. DEAN. I think it could well turn out to be. As, I think, Dr. Matson pointed out, it depends on the marketplace for fission reactors. If, in the year 2000 or even earlier, utilities are buying a lot of light-water reactors, they will want an assured fuel supply and the hybrid could provide them the confidence to order light-water reactors.

I think producing fuel would be an easier market for fusion to compete in, if there is a market, than making electricity, because the electricity market is very difficult to crack. The people who buy electric powerplants want to know that they are reliable, that they will not go off the grid very often, and when you come up with your first generation of fusion reactors there will not be much operating experience so they will be nervous about buying them. So, if you can have an application that generates fissile material or generates hydrogen or something like that, that is off line, you can stockpile it and you do not have this problem that, if the machine shut down every once in a while for unscheduled maintenance, that that really affects your overall economics deliteriously.

In terms of whether the Department's program addresses that, I think the physics and technology in general does support any of these applications. But I do think they need to spend more money on systems design and analysis in order to identify what the unique features are and then, perhaps, start some unique development programs that might be needed for that and I think they have been somewhat remiss in doing that. A couple of years ago fission was so unpopular with the administration that to even talk about this application of fusion was an anathema. I think that attitude has gone away.

Mr. **McCormack**. Mr. Chairman, may I comment on that?

Mr. **Young**. Mr. McCormack?

Mr. **McCormack**. Steve Dean and I have not discussed this concept previously, and I would like to take a slightly different position with respect to it than he has.

I think it would be a bad idea to develop a hybrid, and I recommend strongly against doing so. I think there are overwhelming reasons for not doing so.

In the first place, the Members of Congress and the public conceive of fusion as providing a clean, unlimited resource that is free from the problems of fission products or meltdowns. I think we should keep faith with that concept.

I think that if we need experience in operating fusion plants before we start producing electricity, there are a number of ways to do this other than making plutonium. For instance, fusion machines can be used as a heat source for making alcohol, or making steam for extracting heavy oil from underground. The hybrid was advocated primarily by individuals who were opposed to the breeder, but who wanted to go ahead with their own program for making plutonium. I think it would be a mistake to follow them.

I think that one of the reasons a hybrid looks attractive is because the disadvantages that go with a conventional nuclear towerplant are not taken into account. Today the laws regulating fission plants require that plants be located a long distance from cities; and we are all aware of regulatory delays associated with getting fission plants on the line.

On the other hand, I can easily foresee small pure-fusion machines being placed underground within our cities. There is no reason that this could not be done. There is no significant residual heat or problem of meltdown and the amount of radioactivity associated with a pure-fusion machine, is quite small as compared to a fission plant; and what radioactivity that does exist is in a much more benign form.

Thus it may be possible to eliminate long transmission lines, which are very expensive, environmentally offensive and vulnerable to sabotage. Small fusion plants, located at various underground sites within large cities, could be connected directly to the electric distribution system within those cities. If one takes into account the economics of transmission lines, which I do not think has ever been done when evaluating a hybrid as compared to a pure-fusion plant, the economics would look a good deal more attractive for pure fusion.

Mr. **Young**. Good point. Thank you, Mike.

Mrs. **Bouquard**. Thank you very much, Mr. Chairman.

I certainly appreciate the testimony of you very knowledgeable gentlemen today.

As I was listening to you it seems the only common thread that I see in any of our energy programs as we have discussed our budget issues this year, is that everything we do is piecemeal. There is no continuity in any of our energy programs; we approach everything on a feast or famine basis. In reality we say that we would like to have international cooperation, that we want industrial cooperation, but the very process and the way we go about any of our energy research and development programs, we in effect go against the thrust that we say we want to push forward. I do hope that this administration—all the administrations realize it. We must have a policy on energy that will go beyond a 4-year span.

I was very concerned about the budget, of course, for our fusion program. We have read a lot about the interference of OMB and OSTP and the formulation of this budget. It seems to me—Mr. Kintner, you may be interested in replying to this—Mr. Keyworth's philosophy on fusion is that it has been oversold, has not made much progress in the last 30 years, and that we should redirect our activities to science only. Did you see this sort of philosophy reflected in the budget?

Mr. KINTNER. Well, that is what concerned me most with the circumstances as I saw them and what, eventually, forced me to resign. I had no choice in the matter because I could not lend myself to that kind of a judgment or that basic approach to expenditures of sums of this magnitude.

It does seem to me that the fundamental issue with regard to fusion is whether we are going to work hopefully and deliberately toward practical goals, or we are going to turn the program back to what it was 8 or 10 years ago, a scientific investigation into plasma physics.

Mrs. BOUQUARD. Well, you say that doing basic plasma physics that really $440 million is too much to spend.

Do you think that the program is really being set up for cuts by its enemies within the administration?

Mr. KINTNER. I do not know how to answer that question——

Mrs. BOUQUARD. What sort of cuts might occur?

Mr. KINTNER. I would only observe that if, in fact, one wished, downstream, to make further reductions, putting the program in this particular position makes it far easier to do so, yes. I observed that. I observed it before. I do not know whether that is the objective or not but it clearly does, in fact, put the program in that vulnerable position.

Mrs. BOUQUARD. Suppose we had cuts of $100 million. Would not this pretty well take us back to the drawing board?

Mr. KINTNER. No. We will always have useful experiments going on. We have a broad program. We have a number of very effective organizations at work. There are useful things being done in the rest of the world; we would not go back to the drawing board so far as scientific investigations are concerned. But the science is absolutely useless unless the practical engineering to put it to use is also available not the time that the scientific knowledge is available. That was the basic thrust of the program and the act and that is what I fear is being lost.

Mrs. BOUQUARD. Mike, I could not help but notice the fact that you said that the Magnetic Fusion Energy Engineering Act of 1980 passed with only seven dissenting votes—what a difference from this Congress. I cannot recall any bill with a dollar sign on it passing this Congress with only seven dissenting votes. It has not happened.

Mr. McCORMACK. Have faith.

Mrs. BOUQUARD. I think that all of you stated that $56 million would apparently take care of the underfunded programs to permit the maintenance of the initiatives that were called for in this act, such as $10 million for the Center for Fusion Engineering; $15 million for FMIT; $21 million for EBT–P; and, $10 million for MFTF–B; for a total of $56 million.

Well, let us try a different scenario. Suppose we do not get the additional $56 million. What redirection of funds would you recommend within our constraints of $444 million? Where can we shift? Who wants to answer that?

Mr. McCORMACK. Nobody wants to answer that. [Laughter.]

Madame Chairman, that is something like asking a theoretical question: "in case of a fire, which one of your children would you save?"

I do not think we can answer that question, but each of us may wish to respond.

The success of the fusion program from its very inception has been based upon: (1) the concept of an unlimited source of energy for mankind; and (2) teamwork within and between the laoboratories, thus avoiding cut-throat competition, with someone trying to sacrifice someone else's program. .

No one of us can say, "Well, I will sacrifice this child to save that child." I recognize that this creates a potential hardship for you. I can only say that if you have no choice, if you cannot authorize more than $440 million, then certainly we would be willing to try to help you. However, I do not want at this time to say, and I hope I never have to, what program I would sacrifice in order to keep the program going.

Mr. KINTNER. Can I speak to that just a minute?

Mrs. BOUQUARD. Please, Ed.

Mr. KINTNER. I think that Mr. McCormack's analogy of which child do you wish to get rid of is a good one. Each one of these projects should be recognized for what it is. It is not something that jumped up whole cloth this year. We worked 5 years on selection of a site, on selection of a concept for the Fusion Materials Irradiation Test, on the development of the accelerators, on the architect-engineering work; 5 years and $60 million have been spent as of now on that project. It is like a child, you have now got him through first grade and you do not want to give up on your investment. On the Elmo Bumpy Torus proof of principle we spent a full year trying to decide which one of the various concepts was the most important to our program as a whole, would make a major contribution to the physics understanding and would have the greatest potential from a practical point of view. Then we spent another year—a year and a half—in the competitive process which eventually resulted in the selection of McDonnell Douglas as a lead contractor. That program is 4 years old now; it is not something that is just a creature of this year in this budget.

Similarly, with regard to the Fusion Engineering Device and Center for Fusion Engineering, we studied that question for 6 years and went through a number of cycles until it came down to the present one which was, in fact, accepted by the Buchsbaum Committee and by the Congress as the proper approach, the proper strategy and the proper thrust for future development. So these are not just questions of individual projects.

I think the program must be thought of as a focused, organized, intellectually sound, technically honest program and not as a collection of projects. That, also, is one of the reasons that I felt most important to make an issue out of the changes which were made in the budget this year.

Mrs. **Bouquard**. In listening to your testimony, you mentioned the RIGGATRON concept. Mike, what is your opinion of the merits of the RIGGATRON concept?

Mr. **McCormack**. I think they are excellent, Madam Chairman. I am quite optimistic that the RIGGATRON will succeed in demonstrating a successful fusion reaction in the 1984–86 time frame. I certainly hope so.

I agree with Dr. Don Repici that there are ways that the program can be helped by DOE studies: materials testing for first wall and blanket materials, for instance. Also the DOE can provide computer codes which, as he said, have been paid for by the taxpayers. There may be other similar ways in which the DOE can assist private industry in magnetic fusion RD&D, either with information already in hand or in studies to be done. This should be a DOE policy.

I think of the RIGGATRON as a parallel program with the Federal fusion efforts. I am closer to the RIGGATRON, so I cannot speak as well about the OHTE program, but I think of RIGGATRON and the main line Federal program as insurance against each other's possible failure. We cannot be absolutely certain that either one of them is going to succeed; the odds are that both of them will sooner or later. The question will be: Which one will provide the greater potential for commercial application, and when? Of course, if the RIGGATRON comes on the line first, it will have a profound effect upon all the other energy programs, in every technology anywhere in the world. I am optimistic that the RIGGATRON will succeed, and I wish the INESCO team all the luck in the world.

Mrs. **Bouquard**. Dr. Dean, I received a letter from you recently on behalf of the board of directors of the Fusion Power Associates expressing your concern and their concern as well that our Government is failing to give proper recognition to the potential civilian applications of inertial confinement fusion. What specific energy applications not now being funded would you recommend funding and at what level?

Dr. **Dean**. Inertial confinement fusion, potentially can serve all the energy applications that magnetic confinement can serve in terms of civilian applications. What is needed is systems studies and analyses of these applications for inertial confinement system schemes. I do not know exactly how much money is needed for those kinds of studies. My guess is that it is on the order of $10 million per year. I think they have that amount of money that they could make available for it in their budgets, and there are people working in the field that want to spend that kind of money on those things. The thing that worried us and worried me was that there was some pressure coming from the military committees and the military management saying, "do not work on these civilian applications because this is military money and we do not want you to spend it on these civilian studies." I think that all concerned have to take a little broader view than that. If it is $10 million out of a $200 million program that protects your civilian applications in the long run, one ought not to be so hardnosed as to what color money it is, it seems to me.

Mrs. BOUQUARD. Do you think that this research should be classified such as magnetic fusion research was in the late 1950's?

Dr. DEAN. Absolutely not. I think this classification situation is a disgrace and it ought to be forthwith abolished.

Mrs. BOUQUARD. Thank you very much. Thank you gentlemen. Thank you, Mr. Chairman.

Mr. YOUNG. Mr. Volkmer?

Mr. VOLKMER. Thank you, Mr. Chairman.

I just have a few comments to make and I will ask one question. I appreciate the panel's comments, especially on the hybrid and where Mike fears that might lead us. But that leads me to another thought in looking over the total budget that we receive from the Energy Department and this administration on research and development on all our energy. I am just wondering, do you see any possible competition between those who are promoting the use of fission and breeders and fusion?

Mr. McCORMACK. No, Harold, I do not.

I know that there are some individuals in this country—not very many, but a few—who fear that funding for Clinch River will harm funding for fusion, or funding for fusion will cause cutbacks in funding for Clinch River. I think that is a false premise, and I think that you and this committee should insure that it remains a false premise. I think that each one of these projects must be evaluated on its own merit and funded accordingly.

Mr. VOLKMER. Let me interject a moment.

Mr. McCORMACK. Certainly.

Mr. VOLKMER. We are only going to have so much need for so much electrical energy in the year 2000, 2020, and 2050. If we are able to obtain that energy by use of fusion, then why do we need fission? If we are going to do it through fission, why do we need fusion?

Mr. McCORMACK. I made a presentation on this subject to the January meeting of the American Association for the Advancement of Science, and I submitted that testimony for the record today. I will also provide you with a copy.

To summarize, I will start with President Carter's assumptions for energy requirements for the year 2000.

Mr. VOLKMER. They are probably a little high.

Mr. McCORMACK. Perhaps. Even so, they assume energy consumption equivalent to 2½ times our present coal production and, in addition, 400 nuclear plants on the line, along with the most optimistic scenario for every other energy technology, including oil, gas, solar and geothermal energy, waste conversion and alcohol production. This would still require 400 gigawatts of nuclear power and 2½ times our coal production to make President Carter's conservation target of only 56 million barrels of oil per day equivalent in the year 2000.

Let us assume that magnetic fusion is demonstrated in the year 2000, and that the first practical fusion plant goes on the line in 2005. Assume also that there will be only 1-percent growth per year in total energy consumption from the year 2000 to the year 2070, then total energy consumption will be equivalent to 112 million barrels of oil per day in the year 2070. If we assume that the equivalent of 75 million barrels of oil of that is for electricity, and that only half of that from fusion, that would still require 1,250 gigawatts from fusion. Thus would mean that, starting in 2001, we would be required to have a new 1000 MWe fusion plant on the line every 20 days for 70 years, assuming nothing for replacement of worn-out plants. Now, that is another way of saying we need absolutely every bit of energy we can get, from every realistic technology, from now until sometime in the middle of the 21st century, just to keep up with minimum growth. Most of it will be electricity.

Mr. VOLKMER. Why, necessarily, would you want to replace the fission system?

Mr. MCCORMACK. My personal priorities are as follows:

When fusion becomes available and competitive for generation of electricity, I would immediately terminate the use of coal. I would already have terminated the use of oil and gas except for peaking purposes. I would immediately terminate the use of coal because of the obvious pollution and environmental hazards associated with coal. Then, as each individual fission plant completes its normal lifetime and is ready for decommissioning, I would replace it with a fusion plant, so that by sometime in the second half of the 21st century, we would be fundamentally on fusion. It is obviously a much cleaner source of energy than any other significant option.

Mr. VOLKMER. In other words, you are saying there really is no competition at this time. The competition—it is just a timeframe in which you are trying to utilize different forms to generate electricity?

Mr. MCCORMACK. That is correct.

Mr. VOLKMER. You would still be using fission up to 2050 or 2060?

Mr. MCCORMACK. Yes, and we will be using coal until 2010 or 2020. We need absolutely every bit of energy we can get, from every source we can get, especially for electric energy generation from now on, from this day forward. This is the second most important element of the energy crisis, the first, of course, to reduce our dependence on imported oil and the vulnerability associated with this dependence. However, the need to produce adequate electricity for this country is going to be more and more critical with every passing day.

Mr. VOLKMER. Let me ask you the next question then. Suppose we go back and we follow the administration's proposed budget, and let us assume that 1984 is a lot like 1983. Suppose also that you go along with the assumption that proof of concept is really a demonstration and not basic research and the Government is not to be involved in that. If we continue with this logic for 4 or 8 years, where does that put us with respect to these projects that we need to continue such as the FMIT and the Elmo Bumpy Torus? If we do not do those things, who will? Private industry is not going to do those.

Mr. McCORMACK. Well, unless a private fusion machine succeeds, this country will be in absolutely desperate economic trouble. It will make the present economic problems seem like a Presbyterian Sunday school picnic.

Mr. VOLKMER. After the year 2020 or 2030?

Mr. McCORMACK. We will be in trouble after 1990 with respect to electric generating capacity, and it will keep getting worse and worse and worse.

Mr. VOLKMER. Well, fusion will not be there in 1990.

Mr. McCORMACK. I hope it will be, but we can't count on it. That is why we need to be pushing the fission program and synthetic fuels now.

Mr. VOLKMER. Thank you, Mr. Chairman.

Let me just conclude. In other words, what you are saying is that this extra $56 million on top of the $444 is an investment in the future?

Mr. McCORMACK. Without qualification; and it is probably the most important investment in the future that this Congress could make.

Mr. YOUNG. Just one statement and all three of you can answer or just one.

Is the present level of the private sector's financial and manpower commitment in fusion energy development appropriate at this time, do you think? Any one of the three of you may answer.

Mr. KINTNER. Well, Steve may have a different view than I do on this matter but I think it is not.

By that I mean that it seems to me fusion offers sufficient opportunities for technology development and is sufficiently important to the future that there should be more commitment on the part of industry as of now to its development. They would benefit from it far more than they realize should they become involved. But, it is perfectly obvious also that industry's interest depends upon the interest of the Government; if the Government is interested in fusion from a practical, technologically advanced point of view, then industry will become interested. If it is not, then industry will fall away.

Mr. McCORMACK. May I also answer your question, Mr. Chairman.

I agree with what Ed said. Industry is not going to become involved unless they see that there is a continuing program in which it can participate. We forecast a cost of $20 billion over 20 years. Industry, cannot fund a program of that magnitude. It can—and I think it will—participate more and more heavily if there is a realistic program that has continuity. Of course, INESCO is operating exclusively with private funding, and may succeed before the Federal program.

Mr. YOUNG. Would you like to summarize?

Mr. McCORMACK. Thank you. On behalf of Ed Kintner and Steve Dean, I thank you for inviting us to testify today.

Each of us, in one way or another, has made a personal commitment to the fusion program. In each case, it is without any significant pecuniary reward or promise.

We are here to encourage you to consider several basic facts. The first is that the Congress has always directed the fusion program. It is a strange fact of history that the Congress has always done this in some detail. Starting in 1973, we line-itemed seven or eight items and said, "do this for the fusion program." We have been doing essentially the same thing ever since, including the passage of the Fusion Act of 1980. It included significant detail.

Last year, this committee and other committees of Congress did so again when you rejected deferrals and rescisions requested for certain projects such as the FMIT and the Elmo Bumpy Torus. Nobody has ever run the fusion program as well as the Congress and the Director of Fusion Energy. I do not think it is appropriate to leave it suddenly to someone else whom you don't even know, especially in violation of the law.

Second, the other industrial nations of the world are already moving ahead of the United States in fusion engineering development. This has been going on for the last 12 months. They are increasing the pace of their programs as ours begins to decline.

Third, we emphasize that we are not criticizing the Department of Energy, or anyone in the Department of Energy. You on the committee served with me during the 4 years of 1976 to 1980 when, on several occasions, I commented that the witnesses coming here before us were obligated to say what they and we knew was not really what they believed, but what they were directed to say.

Yesterday you heard testimony from DOE spokesmen who said that they are following the law. That was a misstatement of fact. They are not following the law. They are attempting to cancel the CFE, the FMIT, and the EBT-P; and that is a violation of the law. Nothing they say changes that. Only what you say can change that.

In addition, we are certainly not criticizing anyone in the Congress. We appreciate the difficulties that you face, but, there is a fundamental difference between the philosophies of the Congress and the administration with respect to the fusion program. Remember that the Congress has always supported the fusion program.

When we proposed the Fusion Act in 1980, there were those who said, "You will never get it out of committee, you will never get it through the Rules Committee, you will never get the votes for it, you will never get it out of the Senate, and so forth", but the Congress supported the act because you believed in fusion as the ultimate source of energy.

There is a difference between that philosophy of moving forward with faith in the future—the philosophy of Congress with respect to fusion—and the new philosophy of defeat and disarray that has been written into this budget, imposed upon DOE by OMB and OSTP.

This has created the challenge you face now: whether or not this country is going to go ahead with a program to develop fusion electricity at the earliest possible time; whether we are going to go ahead with a fusion engineering and materials development program. On this point the Congress must be firm.

Thank you very much.

Mr. YOUNG. Thank you, Mr. McCormack.

Mrs. BOUQUARD. I want, again, to thank our excellent panelists for being with us today and for your input into our program. We do want to emerge with an effective energy program.

I would also like to thank Congressman Young for effectively chairing our hearing today. Thank you very much.

Mr. YOUNG. Thank you Madam Chairman.

I want to thank both panels for their candid comments today and I believe your testimony will help us to get back on the right track and make the strong commitment that this country has to make as we try to move into the 1990's and the year 2000.

I think it was very aptly brought out today, so on behalf of the committee, I do want to thank all of you for your fine participation.

The subcommittee will meet again tomorrow, March 25, at 9 a.m. in room 2325 to hear from the Department and non-Government witnesses on electric energy systems, energy storage systems, and small-scale hydroelectric programs.

The hearings for this morning are adjourned.

Thank you very much.

[Whereupon the subcommittee was adjourned at 11:50 a.m.]

[Appendix III, additional statements submitted for the record follow:]

APPENDIX III

ADDITIONAL MATERIALS SUBMITTED FOR THE RECORD

ADDITIONAL REMARKS BY HON. MIKE MCCORMACK

Madam Chairman, I was invited to present a paper on the "Implications of Fusion Energy Development" before the January meeting of the American Association for the Advancement of Science. A slightly modified version of that address is attached for insertion in the record of this Subcommittee's proceeding.

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Although there are many important areas of research and development -- not only in fusion but in many other disciplines as well -- it is no exaggeration, I think, to state that magnetic fusion research and development, especially engineering and materials testing, is now at least as important to the people of this nation, and of the entire world, as any other human activity. I make such a statement with full recognition of the importance of many other areas of research in medicine, biology, genetics, electronics, materials and other disciplines. The fact is, however, that the successful demonstration of a practical, economically competitive fusion electric technology will have a truly profound and almost instantaneous impact upon the entire world.

I am confident that scientific feasibility will be demonstrated in the TFTR and the MFTF-B, as well as such devices as JT 60, JET and a Russian device within the next 3 to 5 years. It was this confidence, and the recognition of the extraordinary potential value to the human race of the development of fusion power that lead the prestigious Fusion Advisory Panel chaired by Dr. Robert Hirsch and the ERAB Panel chaired by Dr. Sol Buchsbaum to idependently conclude in 1980 that the time had come for the United States to move into an aggressive program of magnetic fusion engineering development and materials testing, with the announced goal of building and successfully operating a magnetic fusion electric power demonstration plant by the year 2000. It was the confidence of these two independent panels, each composed of some of the world's outstanding plasma physicists, engineers, research scientists and corporate executives, that this country could succeed in an Apollo-like program to have a magnetic fusion electric power demonstration plant on the line by the year 2000, that generated in us on the House Committee on Science and Technology the conviction that this country should go ahead: that we should compose, introduce and work for the Magnetic Fusion Energy Engineering Act of 1980. It was that conviction that our nation could accomplish the goals set forth in the act that inspired almost unanimous support in the Congress in passing the legislation, in the public in supporting it, and in the Administration in signing it into law.

Setting this nation forth on an intense 20 year, $20 billion program is not a frivilous act. It was undertaken by the leaders of both political parties in the House and Senate, and the Administration after serious consideration of the critical problems this nation faces with respect to providing adequate energy for our people and, at the same time, a recognition of the extraordinary potential that nuclear fusion offers in solving this nation's -- and the world's -- energy problems. It was an act of faith, but it was a serious and deliberate act by responsible leaders of all political, philisophical and economic persuasions. It had almost unanimous support in the Congress of dedicated men and women who concluded that they were, at last, doing something truly worthwhile for this country and for the future. This was an act of statesmanship, deliberation and commitment. It represents the kind of dedication that has made the U.S. a great nation -- and a great people.

The rational for enacting this legislation may be divided into two parts: (1) the critical problems facing this country -- then and today -- with respect to the energy crisis, including the need for a dramatically increased domestic energy production capacity from environmentally acceptable and economically realistic sources; and (2) the limitless source of clean, practical, universally available energy that nuclear fusion offers.

To put the importance of making fusion power available as soon as possible into context, it's necessary to look at the big picture with respect to energy, and then explore the role that fusion will play. This takes us back to the realities of various aspects of the energy crisis. Underlying our concern is the fact that our paramount obligation really is to our country; to its stability, strength and prosperity, and to the freedom, health and continually increasing living standards of our people. Our next concern must be for international stability; for peace, freedom, and higher standards of living for all men and all women everywhere.

This is fundamental, but an adequate supply of energy for the United States and for the other nations of the world is essential to achieving those goals. It is essential for our nation and for our people. An adequate supply of clean cheap energy for all the people of the earth is almost certainly one prerequisite for a chance at world peace.

Our requirements for energy in this country, and for the world, will continue to increase in spite of any conservation program, however spartan and however successful. We will need all the energy we can get, from every realistic domestic source, for as far as we can see into the future. Furthermore, that energy must be as clean, safe and environmentally acceptable; as much as is practical now, and progressively more so with each passing year.

In 1977 President Carter suggested reducing this nation's energy consumption growth rate to about 2% per year between 1977 and the year 2000, thus reducing our total energy consumption from all sources to the equivalent of about 56 million barrels of oil a day in the year 2000 (down from 84 MBOE). President Carter's conservative goal assumed an extraordinarily spartan and successful conservation program, and it assumed a dramatic reduction in our imports of petroleum.

However, the people of this country, and their leaders, seem to have forgotten the energy crisis and the very real hazards that we face because of it. Our dependence on imported oil, and the economic, political and military vulnerability that results from that dependence is the first element of the energy crisis.

In 1981 we imported about 6 million barrels of oil a day, at a cost of about $70 billion and one of the largest trade deficits in history. After all of the political rhetoric about federal spending programs, deficits, inflation rates and tax relief, one fact which is being studiously ignored is that our trade deficits, caused by the importation of oil, are a significant factor in weakening our economy. We continue to be vulnerable to increases in the price of oil -- over which we have no control at all -- and each price increase has resulted in substantial inflationary pressures in this country for months thereafter.

The severe problems associated with the very real political, economic and military vulnerability caused by our continuous dependence on imported oil must be solved in this decade, and it is obvious that fusion energy can make no contribution to solving them. It should be observed, however, that there are programs which, if initiated, could make a significant difference in a relatively short time. In addition to continuing our successes in reducing our consumption of gasoline, we could dramatically reduce the 3 million barrels of oil we burn each day for space heating primarily in residences. This could be accomplished by installing instead heat pumps. They -- and the electricity they use -- would be cheaper over the long run for the homeowner than the oil they burn. Also, we can reduce the amount of oil still being used to produce electricity -- more than a million barrels a day, much of it for base load electricity. This is a scandal, and as much as anything betrays this country's unwillingness to face up to the first problem of the energy crisis.

In the longer run, with batteries perhaps twice as good as the present "top of the line" lead acid batteries, practical electric vehicles could be used as service vans and for commuting. They would be cheaper, far cleaner, quieter and completely practical for this use. By the end of the century, if 25% of our automobile fleet were electric vehicles, we would be saving about one and a half million barrels of oil a day, and U.S. manufacturers might regain their share of the auto market.

The second element of the energy crisis involves the need for adequate energy production capacity from realistic domestic sources -- to allow economic stability and adequate standards of living and national defense during the next 25 years. The 1980 Venice conference of Western leaders concluded that about 90% of the new energy generated between now and the end of the century must come from coal and nuclear fission. This is true for this country as well as the world in general. Other energy sources, including hydroelectricity, solar and geothermal energy and energy obtained from the burning of wood or the conversion of organic materials to useful fuels and energy would, in sum, produce no more than about 10% of our energy requirements during the next two decades.

If, in the U.S., we are to reach the production level set by President Carter's conservation goals, it will still be necessary to produce between 30-35 million barrels of oil equivalent from coal and nuclear fission in the year 2000. This is in addition to optimistic projections for energy production from oil, gas, hydroelectricity, solar and geothermal energy, energy from organic materials, etc. Thus, if we more than double our 1980 coal production capacity, it will still be necessary to have between 300-400 GWe of nuclear power on the line by the year 2000. It is obvious that such goals cannot be reached without the implementation of energy policies and programs involving major commitments which are not now contemplated.

This is a national tragedy. Even with spartan and successful conservation programs in all aspects of private life and in the industrial community, a significant decline in the standard of living of the American people, and a reduction in our industrial production capacity is almost certain to accompany our failure to meet our electric energy production capacity requirements. There is an extraordinarily close relationship between electric energy production, GNP and civilian employment in this country, especially since 1974. Although one cannot easily establish a mathematical proof of a causal relationship between Gross National Product and electric energy consumption, a little common sense helps. Most of our major wealth producing, job-producing industries are energy intensive. Many of them are electric energy intensive. It would be irresponsible at best to ignore these extraordinarily close relationships.

If one assumes that demonstration of fusion electricity will occur in the year 2000, then fusion power can have no impact in helping solve this problem between now and the year 2005. If, however, practical fusion power is demonstrated by 1990 by a small privately developed machine such as an OHTE or a Riggatron, then a beneficial impact -- although small in the total energy picture, could occur by 2000. I am optimistic that the Riggatron will succeed in demonstrating a fusion electric power capacity by 1990. Such a small fusion device would be extremely attractive, if one can be made that is technologically and economically feasible.

There are several apparent advantages that make any fusion electric facility potentially extremely attractive. We are all aware of the unlimited supply of cheap fuel, the freedom from fission-product build-up, and the freedom from the generation of large amounts of heat after shutdown. There are two other advantages, however, that merit mention at this time. One is flexibility. Even if small fusion machines (200 MWe or less) prove to be impractical (for any reason), large machines may still be located near, or even within, large cities, thus sharply reducing transmission line requirements. Transmission costs constitute a significant portion of the total cost of electric energy generation and distribution. They are a constant cause of litigation and controversy, and they are vulnerable to sabotage. Elimination of long transmission lines can be a significant advantage for fusion.

With small machines (fusion only -- not hybrids) we can contemplate locating individual generating facilities at various underground sites near load centers or trunk lines within cities, and connecting to the city's distribution system with super-conducting cable. It may also be practical to combine such facilities with super-conducting storage rings for peaking power requirements. Such an advantage for small fusion machines should make them extremely attractive.

There remains the *third element of the energy crisis*. It relates to environmental protection and to resource conservation. This nation, and the world, must -- as soon as possible -- sharply reduce the burning of fossil fuels to produce energy. This is obviously not possible now, and the rate of reduction will depend on many differing factors in each country. However, it must be our stated goal, if we are to protect our atmosphere from unacceptable levels of pollution, and our world from the Greenhouse effect; and if we are to protect our petrochemical resources from thoughtless depletion. They should be saved for future generations, and we should encourage other nations to accept this philosophy.

In this country, we should plan to limit the use of petroleum products and natural gas for the generation of electricity to peaking power only, and then only when such fuels are the most practical and economical. The use of oil and natural gas for residential heating and hot water should be discouraged, except when it is clearly cheaper and more practical than electricity, electric heat pumps or solar assisted heat pumps and hot water systems, or some combination thereof.

We have no choice but to depend upon coal for the next three or four decades for electric energy production, but this use should be phased out as soon as practical. Until that time, a maximum effort must be mounted to produce clean fuels from coal, and off-gas cleaning systems must be continually improved to reduce air pollution. Of course, it is impossible to know what the actual impact of the Greenhouse effect will be, or when it will appear. Hanging over our heads, however, is the possibility that we will "go over the cliff" without knowing it until it is too late, overload the world's atmosphere with carbon dioxide, and inflict terrible environmental damage on our world, from which it may take centuries to recover.

Our conventional nuclear power industry, backed by a future breeder program is, of course, our mainline protection today against environmental damage from the burning of fossil fuels, but just as doubling our present coal production by the year 2000 will still require having about 400 GWe from nuclear fission on the line by that date, so too will having 400 GWe of nuclear power on line still require us to about double our coal consumption -- or suffer crippling damage to our economy and our standard of living from loss of electric production capacity.

So we must depend upon both coal and nuclear fission until fusion power can begin to make its contribution. When this occurs, and if we can install electric production capacity sufficient for our needs, then we can start phasing out coal plants. Of course, no new coal plants should be started, once fusion power is available.

The implications of a successful program to develop fusion energy cannot, of course, be discussed in a vacuum. Every new energy source or technology must compete in a complex marketplace with all of the others. In addition, significant penetration of the energy market, even by a superior competitor, seems agonizingly slow, even under the best of conditions. Let us assume, for instance, that magnetic fusion electric generation is demonstrated in the year 2000, and that it is, for one reason or another, superior to every other energy source or technology. Let us then assume that, starting in the year 2001, a policy is established that all new energy generating facilities shall be fusion plants. Let us assume also that energy consumption in the United States will be equivalent to 56 million barrels of oil a day from all sources in the year 2000 -- equivalent to about 1850 GWe capacity from plants operating at 33% thermal efficiency and 67% load factor. If we assume only a 1%/yr. growth rate for total energy consumption starting in the year 2000, then our total consumption would be 112 MBOE in the year 2070. If we assume that 75 MBOE of our energy consumption is for electricity in the year 2070, and half of that from fusion, this would require 1250 GWe from fusion, or one new 1 GWe plant on the line each 20 days for 70 years. This schedule does not consider replacement of early fusion plants or the number of small plants required to total 1250 GWe.

Whether or not such a scenario is even remotely realistic may be debated at length, but I suggest that it may prove to be conservative. In addition, it emphasizes why it is so important to move toward a demonstration of practical, competitive fusion power as soon as possible.

There are other aspects of early demonstration that are important to consider. Many of our utilities are almost paralyzed today, failing to plan for the future because of regulatory and economic problems. They find it extremely difficult to plan to build new plants. No new nuclear plants, and only a handful of coal plants, and some of these quite small, have been ordered in three years. Still the demand for electric production capacity continues to grow, and the percent of reserve production capacity dwindles toward brownouts and blackouts. The Electric Power Research Institute predicts that if GNP grows at the rate of 2.5% to 2.9% per year from 1980 to 2000, then electric energy consumption will grow at 3.3% to 4.2% per year during that time. A growth rate of 3% per year would mean doubling in 23 years.

As I have observed, fusion power can make no contribution during this century unless a small machine such as OHTE or Riggatron is demonstrated by the year 1990, and only a small percent by the year 2000, even in that case. However, the demand will be there as soon as fusion power becomes available, and it will be tremendous.

In addition, I believe that demand will grow in foreign nations, including some of the poorer ones, and that the anticipation that fusion power will be available will have a salutory effect on our relations with such nations.

It is interesting to observe that within only a few weeks after our legislation was signed into law in October, 1980, the Japanese reviewed their magnetic fusion program and promptly committed their country to an accelerated schedule for engineering development and materials testing, with goals quite similar to those expressed in our law. The European Economic Community appointed a blue-ribbon review committee even before the end of 1980. By June of 1981, the committee had recommended an accelerated program in engineering development and materials testing, and increased funding to support it.

Unfortunately, both the Japanese and the E.E.C. are dependent on the partially completed Fusion Materials Irradiation Test Facility at Hanford. This is one of the projects that some individuals in the OMB are attempting to kill -- in spite of the fact that it is absolutely critical to our federal program, and is urgently needed by the Japanese and European Community. It is the only such machine in the free world, and the Congress specifically directed in the recently enacted appropriation law for fiscal year 1982 that construction continue.

Now the Administration again proposes to kill the FMIT and the EBT-P. It also is ignoring the directive in the law to move forward with creation of a Center for Fusion Engineering to guide the research and development leading to construction of a fusion engineering test bed (the Fusion Engineering Device) by about 1990, and then a Magnetic Fusion Demonstration Plant by the year 2000.

The refusal of the OMB to comply with the law is, from my perspective, a major tragedy for the world. Not only does it inflict great damage on the federal program, it creates confusion among our foreign friends in Europe and Japan who first followed our lead and relied on this country for cooperative use of partially completed facilities, and who now don't know how to deal with an unreliable ally -- or how to proceed without critical facilities.

Just as important, failure by the Administration to follow the law is disillusioning for scientists and executives of interested industries, and for the young citizens of our nation who looked to the fusion law as a beacon of hope for their future.

I think it is important to recognize that if we bestir ourselves, magnetic fusion power is within the grasp of the human race, and that its potential for benefiting humanity staggers the imagination. I have stated that when we step across that line with the first demonstration of fusion electricity it will constitute the second most important event with respect to energy in human history -- second only to the discovery of fire. The advent of controlled fusion will stand out as a giant step in the march of mankind toward true civilization.

Above all else, fusion is a technology that we can share with every human being in the world. It crosses all political boundaries. Clearly, every single person in the entire world benefits when everyone has the energy he needs, and from that energy, the water and materials that he needs.

Just as fusion is the ultimate source of energy in the universe, so it will be here on earth. When and how this happens is up to us, and the future of mankind, during the lifetimes of our children, will be profoundly affected by what we do now.

Thank you.

MIKE McCORMACK

BIOGRAPHICAL SKETCH

Residence: 508 A Street, S.E.
Washington, D.C. 20003
(202) 544-0254

Spring, 1982

Born: 14 December 1921, Basil, Ohio
Military Service: Parachute Infantry Rifle Platoon Officer - WW II.
Education: B.S. and M.S. (1949) in Chemistry, Washington State University.
Primary Professional Activity: Research Scientist, Hanford (AEC) Facility 1950-1970.
Family: Married (1947) to Margaret Higgins of Toledo, Ohio; three adult sons.

Mike McCormack served in the Washington State House of Representatives (1956-60) and Senate (1960-1970). He authored legislation creating a new state community college system, a modern authority for industrial development by port districts, and a thermal power plant siting law (which is a model for other states).

McCormack was elected to Congress in 1970 and served through 1980. He was a member of the Committee on Public Works and Transportation and the Committee on Science and Technology; and was Chairman of the Subcommittee on Energy Research and Production.

McCormack is widely recognized for his leadership role in energy-related matters during his service in the Congress. His expertise in all fields of energy is respected today among members of both political parties, by the White House and the Department of Energy, and by industrial and labor leaders.

The following federal laws were conceived, written and sponsored by Mike McCormack:

Public Law 93-409, the Solar Heating and Cooling Demonstration Act of 1974.

Public Law 93-473, the Solar Energy Research, Development and Demonstration Act of 1974.

Public Law 93-410, the Geothermal Energy Research, Development and Demonstration Act of 1974.

Public Law 94-413, the Electric and Hybrid Vehicle Research, Development and Demonstration Act of 1976.

Public Law 95-39, the National Energy Extension Service Act (with Congressman Ray Thornton of Arkansas).

Public Law 95-238, the Automotive Propulsion Research and Development Act of 1977 (with Congressman George Brown of California).

Public Law 95-590, the Solar Photovoltaic Research, Development and Demonstration Act of 1978.

Public Law 96-386, the Magnetic Fusion Energy Engineering Act of 1980.

Public Law 96-567, the Nuclear Safety Research, Development and Demonstration Act of 1980.

In Addition:

McCormack has been the leader in the House of Representatives during the period 1977-80 in the campaign to preserve the nuclear breeder program and to move forward with nuclear energy development within the U.S.

In 1979 and 1980 McCormack sponsored realistic legislation for the handling of low-level nuclear waste and a series of demonstrations for the geologic storage of glassified high-level nuclear waste. These bills were delayed in other committees, and did not become law.

Honors:

Awarded an honorary Doctorate in Engineering by the Stevens Institute of Technology (1976).

Elected a Fellow by the American Association for the Advancement of Science (1980).

Elected a Fellow of the American Nuclear Society (1980).

Elected a Fellow of the American Institute of Chemists (1980).

Received the "Centennial Award" of the American Society of Mechanical Engineers (1980).

Received the Distinguished Public Service Award from the Institute of Electrical and Electronics Engineers (IEEE) (1980).

Received the Legislative Recognition Award from the National Society of Professional Engineers (1980).

Designated "Solar Energy Man of the Year" by the Solar Energy Industries Association (1975).

Received the 1976 Distinguished Service Energy Award from the National Energy Resources Organization (NERO).

Received the "Triple E" Award from the National Environmental Development Association for "significant contribution" for balance in energy, environmental and economic issues (1976).

As a private citizen in 1981, McCormack:

- Served on Secretary of Energy Edward's Task Force on the New Administration's Energy Policy (NEP-III).
- Accepted Appointment to the:
  - National Research Council's Space Advisory Board.
  - General Accounting Office's Committee on Program Evaluation
  - The Fusion Advisory Panel serving the U.S. House of Representative's Committee on Science and Technology.
- Was elected to Membership on the Board of Director's of the Universal Voltronics Corporation of Mt. Kisco, New York.
- Was named by Technology magazine as one of the top 100 innovators in the world in the year 1981, "... without whom some important technical advance during the past year would not have occurred."

In 1982, McCormack founded a new corporation: McCormack Associates, Incorporated, offering consulting services in science, energy, government and public information.

McCormack has written hundreds of papers and public addresses on energy, primarily designed to help the public understand the basic facts concerning energy, with special emphasis on nuclear energy and nuclear safety issues.

McCormack is frequently requested as a spokesman by electric utilities, the Edison Electric Institute and the Committee for Energy Awareness. Recent addresses by McCormack include:

- "America's Energy Future" (Professional Advisory Council on Energy, Philadelphia, 16 Feb 82).
- "Implications of Fusion Energy Development" (American Association for the Advancement of Science, Washington, D.C., 7 Jan 82).
- "Helping the Average Citizen Understand and Accept Nuclear Power" (American Nuclear Society, San Francisco, 1 Dec 81).
- "We, Who Are The True Environmentalists" (American Nuclear Society, San Francisco, 2 Dec 81).
- "Getting Priorities Straight on Energy" (American Power Conference, Chicago, 28 Apr 81).
- "The Urgent Need for Realistic Planning Now" (International Scientific Forum on Geopolitics of Energy, Fort Lauderdale, 10 Nov 80).
- "Facing The Facts About Energy" (Soroptimist International of the Americas, Denver, 24 Jul 80).

STATEMENT OF DR. JOHN B. YASINSKY
WESTINGHOUSE ELECTRIC CORPORATION
BEFORE THE
U.S. HOUSE OF REPRESENTATIVES
COMMITTEE ON SCIENCE AND TECHNOLOGY
SUBCOMMITTEE ON ENERGY RESEARCH AND PRODUCTION
MARCH 24, 1982

MADAME CHAIRMAN,

I am John Yasinsky, General Manager of the Advanced Power Systems Divisions of the Westinghouse Electric Corporation. Our company is involved in the development of a broad spectrum of advanced energy technologies, which include both the liquid metal cooled fast breeder reactor and nuclear fusion. Through our Advanced Reactors Division, we play a lead role in the Clinch River Breeder Reactor Project, and Large LMFBR Plant studies. Through the Westinghouse Hanford Company, we operate the Hanford Engineering Development Laboratory for D.O.E., including responsibility for the Fast Flux Test Facility and the Fusion Materials Irradiation Test Facility (FMIT).

Our position in support of the fast breeder is well known; at this time I would like to acquaint you with our equally strong support of, and interest in, the timely development of fusion technology. Westinghouse has been active in the development of fusion technology since the early 1950's. We are currently involved in all aspects of the national fusion program, ranging from the manufacture of components for the Tokamak Fusion Test Reactor to the conceptual design of fusion power plants involving a variety of alternative confinement approaches. These activities are indicative of our strong support for the fusion program and particularly our endorsement of the aims of the Magnetic Fusion Engineering Act of 1980.

We recognize the limited government funds available for the development of advanced energy technologies must be used prudently. Nevertheless, short range economic evaluations cannot be the sole basis for near-term decisions affecting our future energy supplies because there are inherently large uncertainties associated with the availability and competitive position of primary fuels and advanced energy technologies over a period of 2-3 decades. A national energy policy that depends heavily on economic projections, major discoveries of domestic energy resources and/or technological breakthroughs entails substantial risk that our country will not have an adequate and reliable supply of energy in the future. Accordingly, the U.S. msut pursue a supply strategy that provides for a mix of energy sources which will permit our various consumption sectors to accommodate a broad range of political, economic and technological developments.

As a consequence we see a strong incentive for the simultaneous pursuit of both the LMFBR and fusion technology. In view of the large difference in technological maturity and potential deployment time frame for these two energy generation technologies, we see no explicit conflict in promoting the development of both technologies as part of a prudent and broad based national energy policy.

On the basis that LMFBR technology is ready for commercial demonstration and that nuclear fusion is still in the early stages of engineering feasibility, we believe that the emphasis in the Administration's FY-83 budget request on the LMFBR program is technically and strategically sound. However, this does not imply that the fusion effort should be de-emphasized in any way. In fact, we would recommend that careful consideration be given to augmenting Administration's FY-83 budget request in the magnetic fusion area to continue several important technical initiatives which are vital to expediting the transition from a physics-based program to an end-product focused engineering development effort. Key program elements in this regard are the Fusion Materials Irradiation Test Facility and the definition of an appropriate Fusion Engineering Device to provide a strong focal point for near-term engineering development activities. Many of the major technological questions facing fusion today, such as reactor size, complexity, and cost can only be addressed in the context of such hardware development, test, and demonstration programs.

The impressive progress in the magnetic fusion energy experimental program to date has generated great confidence that the United States will ultimately achieve the conditions necessary to generate electrical power from fusion. However, an essential engineering step which must be taken is the development of materials to withstand the intense neutron environment of fusion power devices. The fusion environment is extremely harsh on existing alloys. Without improved materials, fusion plants would operate well below desired levels and would not be economically viable. In order to develop improved materials the fusion community has devised a strategy to take alloy data from fission reactors and translate these to fusion reactor conditions using the FMIT. Without FMIT the application of the fission data is not possible and alloy development and engineering characterization for fusion could not be completed. In short, without FMIT, fusion commercialization is jeopardized.

The first fusion reactor plants, such as FED or Demo, cannot substitute for FMIT in the development of a high energy neutron radiation effects data base. While these plants are appropriate for many engineering problems they will require 10-20 years to do what FMIT can do in 2-3 years. The alloy development process requires a series of scientific investigations followed by testing in service-like conditions, and final optimization. Such a process would take as long as 50 to 70 years in a fusion plant, far too long for practical success.

If fusion commercialization is to be achieved as early as possible then, we must proceed rapidly through the engineering development phase. Operation of FMIT by 1987 is absolutely required to complete this effort.

The FMIT Project, once again, continued to make outstanding progress this past year. A major accomplishment was the recent completion of the design of the building and utilities portion of the facility by the R. M. Parsons Company in California. This engineering effort successfully incorporated the individual designs of the accelerator, target, handling and control systems into an integrated facility design. This means that the facility is ready for construction as soon as funds are available.

The Accelerator Division of the Los Alamos National Laboratory (LANL) joined the Hanford Engineering Development Laboratory (HEDL) in an outstanding cooperative effort to design and develop the FMIT. International acclaim in accelerator technology has been achieved with development of the FMIT advanced low-velocity accelerator, known as the radio-frequency quadrupole (1981 IR Award). At HEDL, the World's largest liquid lithium test loop has operated with extreme reliability for more than two years demonstrating the performance of lithium system components and the unique lithium "target". Consequently the outstanding technical risks are small.

Fabrication of accelerator and lithium system equipment in underway in California, Ohio, Texas, Maine, Minnesota and Washington. Approximately 55% of the accelerator equipment is under contract. Delivery to HEDL has already started and all vendors are proceeding on schedule and within budget.

Fifteen of the 77 accelerator drift tubes will be completed at HEDL this summer. A major component, the prototype radio-frequency power supply, is now under final test at Hanford. One critical lithium component, the electromagnetic pump, has already been completed and another key component, the lithium-to-organic heat exchanger, is in fabrication at Southwest Engineering Corporation in California.

The FMIT has achieved a high degree of momentum with the completion of facility design and a substantial amount of procurement either complete or in process. Site preparation has been completed and the project stands ready to initiate construction activities.

The FMIT Project has all the ingredients necessary to assure success:

- The technical feasibility has been demonstrated through the research and development programs.

- A proven management team is in place.

- Highly qualified technical personnel at HEDL and LANL.

- Project management systems necessary to control budgets and schedules are in place.

- The project scope and requirements are well defined.

By the end of Fiscal Year 1982, approximately $80M or about 40% of the total program funds will have been allocated. I strongly recommend continued funding in Fiscal Year 1983 to maintain project momentum to capitalize on the investment already made. Two options are viable. The first would be to proceed with construction and procurement, this would require a funding level in 1983 of $25-30M. If this budget is too difficult then a second option would be to proceed to complete equipment design in preparation for a 1984 construction start.

If the United States makes the commitment to start construction and complete the project on a timely basis major funding from foreign participation seems assured. In this event the remaining U.S. commitment would be less than the amounts committed to date.

It is absolutely mandatory to have an FMIT facility in order to achieve a practical fusion machine. In view of these factors, disbanding of the management and technical team with a plant ot reestablish the team at a later date in fraught with great risk. Therefore, from both technical and management viewpoints the continuation of the FMIT project is strongly recommended by the Westinghouse Electric Corporation. This is the most cost effective approach in the use of limited government resources.

DR. JOHN B. YASINSKY
WESTINGHOUSE ELECTRIC CORPORATION

Dr. John B. Yasinsky is General Manager of the Advanced Power Systems Divisions of the Westinghouse Electric Corporation. Joining the corporation in 1963, Dr. Yasinsky was assigned to the Bettis Atomic Power Laboratory, working in reactor theory, design, dynamics and control in support of the naval nuclear program. In 1971 he was named manager of electric systems and plant analysis at Bettis.

The following year John was named to the White House Fellows Program and served as Special Assistant to the U.S. Secretary of Commerce.

Returning to Westinghouse, Dr. Yasinsky was named Manager, Business Development for the Breeder Reactor Divisions, moving through a variety of marketing management jobs. In 1978 he was appointed Director of the Advanced Coal Conversion Department which was responsible for the firm's activities in low and medium BTU coal gasification research and development.

Appointed President of Westinghouse Hanford Company in January 1979 he was responsible for the operation of the Hanford Engineering Development Laboratory for the U.S. Department of Energy. A major responsibility there is also the operation of the Fast Flux Test Facility for testing breeder fuels and materials. Work is also underway on developing and testing materials for fusion reactors.

He was appointed to his present position in August of 1980. In this post he is responsible for the Advanced Reactors Division, the Westinghouse Hanford Company and the Advanced Energy Systems Division.

Dr. Yasinsky received his B.S. in physics from Wheeling College. He earned a master of science degree in physics from the University of Pittsburgh and his Ph.D. in nuclear science from Carnegie Institute of Technology (now Carnegie-Mellon University). He has authored numerous technical papers and reports and taught in the graduate programs at Pittsburgh and Carnegie Mellon. Dr. Yasinsky is a member of the American Nuclear Society, the National Security Industrial Association and has served on the Advisory Council of the National Energy Resrouces Organization. He is a member of the White House Fellows Association.

UNIVERSITY OF WASHINGTON
SEATTLE, WASHINGTON 98195

College of Engineering
Department of Nuclear Engineering

March 17, 1982

Honorable Maralyn L. Bouquard, Chair
Subcommittee on Energy Research
and Production
Committee on Science and Technology
U. S. House of Representatives
Suite 2321, Rayburn House Office Building
Washington, D. C. 20515

Dear Congresswoman Bouquard:

We are writing on behalf of the University Fusion Association. Our organization represents 48 universities with 170 members engaged in fusion research, mainly through DOE funding.

We have been unable to arrange to testify at your subcommittee hearing next week. However, we wish to provide the following statement for the record.

In present more limited fusion funding budgets are projected to be "flat" over the next few years. University programs, representing $41M, or 12 percent, are a very cost effective element of the magnetic fusion effort.

A unique contribution of the universities is training of fusion scientists and engineers. Under 66 separate contracts 70-80 new Ph. D.'s per year are trained and placed for the most part in the fusion power industry, national laboratories and universities.

The university programs have an impressive record of research results, critical technical review and new ideas for the main line fusion efforts and new approaches. This comes both from small, single-investigator projects and larger university programs.

Broadly speaking, the administration's FY 1983 budget preserves the base fusion program in Confinement Systems, Development and Technology (D&T) and Applied Plasma Physics (APP) while putting some large advanced projects, FMIT, EBT-P, CFE and part of MFTF-B, on "hold" for more favorable future funding.

The university programs are very vulnerable to funding shifts between base programs and projects. The APP and D&T university programs are down to basic, salary-intensive funding in most cases. We hope

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that additional funding can be provided for important large projects. However, relatively small funding shifts in the presently proposed FY 1983 fusion budget could wipe out many university programs. Once students are turned away, considerable time would be required for them to return to fusion and an even longer time to complete the training necessary to maintain the flow of trained personnel. University programs cannot be turned on and off like a water faucet.

For these important reasons we urge support for the university programs in the fusion budget your committee is considering.

Sincerely yours,

THE UNIVERSITY FUSION ASSOCIATION

Fred L. Ribe
Professor of Nuclear Engineering
The University of Washington
Chairman

J. Leon Shohet
Professor of Electrical and
Computer Engineering
The University of Wisconsin
Vice Chairman

George H. Miley
Professor of Nuclear Engineering
The University of Illinois
Secretary-Treasurer

FLR/JLS/FHM:mt

cc: Executive Committee

STATEMENT ON FY83 AUTHORIZATION FOR MAGNETIC FUSION

BEFORE THE

SUBCOMMITTEE ON ENERGY RESEARCH AND PRODUCTION

OF THE

HOUSE COMMITTEE ON SCIENCE AND TECHNOLOGY

MARCH 23, 1982

BY

THE FUSION ENERGY FOUNDATION

The Fusion Energy Foundation, a nonprofit, educational organization with more than 20,000 members in the United States committed to the application of advanced technologies to the achievement of economic growth, submits this statement on the fiscal year 1983 nuclear fusion budget in the belief that the members of this committee face a task of awesome significance for the future of the United States. We believe that the fusion budget line, although it has never been quantitatively even 1 percent of the federal budget, makes a qualitative contribution to the future well-being of the nation that no other item in the federal budget does. Our testimony outlines the importance of this item not only in scientific and technological terms, but in the much larger economic and national security terms that have concerned foundation members over the past year.

The federal budget for FY1983 is unique in being entirely dependent on the current economic situation for its realizability. If interest rates continue at their present heights, the federal budget deficit arising from interest payments alone willwreck the positive programs in the budget. For the first time in decades, the President did not actually make the budget; the budget was determined by the policies of the Federal Reserve Board and Federal Reserve head Paul Volcker's hidden agenda for "controlled economic disintegration."

This budget and its debate by Congress thus labors in an atmosphere of a certain unreality--the real policy determinants of the budget process are being debated in the halls of the Federal Reserve Board, not those of Congress. The Fed has assured the country that a recession--called by its right name a depression--is necessary for the country's economic health, that a "shakeout" of American industry would be beneficial, that 8 percent unemployment is unavoidable, and that a falling living standard is actually good for us all.

Unless reversed, the Federal Reserve's policies are certain to cause a collapse of federal revenues by mass bankruptcies and unemployment before Oct. 1, 1982, and a budget deficit of $250 billion or more for fiscal 1983. Such a deficit will destroy the current budget, whatever its particular inadequacies. But should Congress and the President reverse Federal Reserve policy, the debate on the budget would become healthy. A budget far superior in its impact on national well-being and national progress could then be shaped.

Our testimony before this committee is based on the results of a series of detailed studies conducted by the Foundation over the past three years. These studies have shown the following:

(1) The most significant single cause of the economic and social decline of the United States in the past decade is the lack of a "science driver" for the economy. With the demise of the Apollo program and NASA's fulfillment of that role in the late 1960s, the country has been without a commonly perceived, well-funded advanced scientific-technological program to guide education, to power technological innovation in industry, and to inspire the youth of our country.

(2) This lack of a "science driver" has combined with increasing obsolescence in industry, monstrously high interest rates, a plague of drug addiction, and falling birth rates to produce the current depression.

(3) The consequence of this situation is a serious and continuing decline--as measured by any but the most self-consoling analysts--in national security. We have today a military capable of, and prepared for, fighting only the most localized conventional wars, with the objective of controlling natural resources. Today, the traditional American military dedicated to the mission of "nation building" does not exist.

(4) To remedy this increasingly grave predicament

requires a combination of policy initiatives. We have concentrated in this testimony on the critical role that science policy, specifically policy concerning advanced energy research, can play in changing the direction of this country. The studies we have conducted document our conclusion that a program for fusion energy development, like the one mandated in the Magnetic Fusion Energy Engineering Act of 1980, would provide a large measure of the "science driver" required to renew the American economy.

We have provided a detailed budget proposal for advanced energy research and specifically a budget for fusion research, in several attachments. An adequate advanced nuclear research budget requires the expenditure of $500 million more than what is proposed by the FY1983 administration budget. For magnetic fusion, we believe that a budget of $660 million (rather than $450 million) should be invested, to fulfill the mandate of the Magnetic Fusion Energy Engineering Act of 1980. This investment would be the first step toward the engineering realization of nuclear fusion--a clean, safe, limitless source of the most concentrated energy man has ever mastered.

THE ECONOMIC BACKGROUND

All "American System" economists, from Alexander Hamilton through Henry Carey and E. Peshine Smith, have agreed that the most palpable measure of an economy's health is its ability to utilize "artificial labor" or the "gratuitous power of nature." In the early 19th century, these economists established the very modern-sounding thesis that energy and its concentration by means of new technologies was the embodiment of economic health and progress. They also established that the most accurate measure of this health or progress potential was provided by quantifying the population potential of such an economy. Lyndon H. LaRouche, Jr., noted economist and a member of the board of directors of the Foundation, has termed this measure "relative potential population density."[1] That is, the most important indicator of the success of an economy is the number of people that can be (potentially) supported in a manner that not merely continues the present living standards for them and their descendants, but in a manner that makes possible continued progress. Equilibrium or zero-growth (a "sustainable future" is the misnamed term of the modern-day Malthusians) is not a possible future. The only adequate measure of economic policy is whether it fosters continued progress.

The Fusion Energy Foundation has conducted a number of econometric studies on the relation between energy and potential population density, and the conclusions of these early American economists have been borne out in the most precise detail. Perhaps the most graphic indication of the close relation between energy and population is provided by a recently completed study of the role of advanced energy use globally in the past 15 years. Using the LaRouche-Riemann econometric model, a large, computer-based model that has an engineering rather than a financial structure,[2] the Foundation conducted a set of comparative scenarios for the global economy by varying the mix of energy sources used during this period. Taking the actual economic history of the past decade and a half as a base scenario, we measured the economic and demographic impact of different energy production technologies.

The results of the high-technology scenario merit special attention. Taking as a possible high-technology scenario the projections for the use of nuclear energy developed by the Atoms for Peace planners in the late 1950s and early 1960s,[3] the LaRouche-Riemann model and its energy submodel were used to analyze the economic impact of the accelerated adoption of nuclear energy. This analysis showed that economic growth during the past 15 years could have been increased on the average 3 percent per year globally over the rate actually achieved had maximum use been made of conventional nuclear energy and associated technologies. There are two interconnected reasons for this substantial improvement in economic growth, both characteristic of advanced technologies:

First, more advanced technologies are cheaper. In the case of nuclear energy this was true even before the oil crisis of 1973; after 1973, nuclear energy became even more economically advantageous. The refusal to use nuclear energy on the part of some advanced countries, and the denial of nuclear energy to many underdeveloped countries was, in economic terms, a subsidy to the more expensive forms of energy like oil and coal, and thus a tax on the world economy. This tax on the world economy resulted in a small, almost constant depression of possible growth rates, as desperately needed capital during the 1970s was used to pay unnecessarily high energy costs. The impact was especially severe in the developing sector.

Second, advanced technologies spur general productivity increases. Although this is less important in the first 5 to 10 years of this period, in the long term new technologies like nuclear energy had a significant impact on productivity. More than 2 percent of lost economic growth in our analysis resulted from lost increases in productivity on a world scale, because the world used the more labor-intensive technologies associated with coal and oil, or the even more labor-intensive and inefficient technologies associated with conservation and solar energy. For the advanced sector specifically, our studies estimate that for every 1,000 megawatts produced with an advanced technology, there is a 0.01 percent increase in the average productivity that will not occur if that same energy (even at the same price) is produced by coal or oil. This effect is well known from the Apollo program,[4] and is the most significant economic impact of any advanced technological project, including military ones, in the advanced sector.

The LaRouche-Riemann model was then used to measure the demographic impact of this depressed economic growth in the developing sector. It is well known that economic well-being is closely connected with life expectancy, fertility, and supportable population levels. Using the population submodel of the LaRouche-Riemann model, we arrived at an estimate of the demographic consequences of substituting oil, coal, or conservation for a more advanced energy source such as nuclear: Approximately 115 *million* people worldwide *died* unnecessarily. In other words, 115 million people were alive in 1965 who would still be alive today had the world economy benefited from an aggressive program of nuclear energy use. These are people--about 35 percent of whom would be economically active today--who died before the age of 25. The other 65 percent represent perhaps an even greater tragedy, for they died as children.

These 115 million people did not, of course, die from lack of electricity. They died from malnutrition, disease, poor sanitation, inadequate housing--the typical conditions of underdevelopment that depress life expectancies and raise infant mortality. Advanced technologies are the cure for these economic diseases. To avoid the use of these technologies, for whatever reason, is to condemn literally tens of millions of people to death every year.

This analysis estimates that a continuation of the present antinuclear policies of the United States will condemn another 135 million people in the next decade. The enormity of such a policy is difficult to comprehend.

The impact of advanced energy technologies in the advanced sector is, of course, different from that in the developing sector. The demographic impact in the advanced sector is not as grisly or as easily measured, but the economic impact is even greater. The Foundation has conducted a number of studies of different aspects of the connection between advanced technologies and economic health; the most relevant of these for the present testimony concerns the role of infrastructure development, advanced technologies, and electricity production. This recently completed study shows that there is a complex, synergistic interaction among these three aspects of an economy, in which a decline in any of the three accelerates causal factors that depress indicators of the other two, leading to calamitous declines in the ability of an economy to reproduce the material prerequisites for continued existence.

However, we concentrate here on the policy implications of the study in which we examined the consequences of implementing a concerted program of infrastructure development, advanced scientific and technology research programs, and accelerated electrical energy production. A sequence of historical analyses using the LaRouche-Riemann model data base showed a striking correlation between gross expenditures on infrastructure (roads, canals, water systems, and so on) and the "gross reproductive capacity" of an economy. This measure of an economy's general thermodynamic efficiency is unique to the LaRouche-Riemann model and is calculated as a ratio of the gross tangible profit in an economy to the total of that economy's tangible output that is devoted to the equilibrium reproduction requirements. This generalized measure of productivity shows that infrastructure development has a much more profound impact on economic growth than the improvement of communication or transportation usually associated with it. Infrastructure does not produce tangible output; it produces productivity.

Especially critical in this is the role of electricity. Electricity as an energy carrier is a specific part of infrastructure; it does not produce energy, but it carries energy in a way that encourages productivity growth. Several recent studies by other energy analysts have shown a similar critical role played by electricity.[5] One of these studies concludes that electricity growth paces economic growth (as measured by gross national output), and that electricity growth is always 2 percentage points greater than overall economic growth. This analyst summarizes his findings as follows: "Electricity growth is, practically by itself, the 'locomotive' of GNP growth whereas non-electric energy, while basic to the economy, has very little relation to growth. At this time, we shall note that the growth in electricity use must either outpace economic growth by two percentage points or progress at a 50 percent faster rate, as the case may be."

In policy terms, then, the question is one of how to increase electricity production. The results of our studies are unequivocal: The cheapest and most advanced technology must be used. This is nuclear energy. We summarize below some specifics of our program for nuclear energy production, but in a more general context, the production of nuclear energy is only the first step in an economic policy constellation designed to reinvigorate the U.S. economy.

As Alexander Hamilton especially stressed, it is not enough to produce more; an economy must also produce the conditions for new technologies, and it must produce the prerequisites for further growth. The genius of this "American System" approach to economic development is that the process of research and development on these new innovations that ensure continued progress itself improves present production techniques, education, and general productivity. This role of new technologies was dramatically shown in the course of the Apollo program. In outline, this dual role is the importance of advanced research projects like the fusion research program.

Fusion is certainly the natural successor to conventional nuclear technologies; its significance as the next century's energy source of choice is the basis of the Magnetic Fusion Energy Engineering Act of 1980. But, fusion research itself, in a sense separate from its realization as an energy producer, provides a long list of potential benefits for the American economy. Among the most exciting areas are new materials, new methods for handling high temperatures, new vacuum technologies, new superconducting processes, new magnet technologies, automation advances, high-speed control and electronics, insight into high pressure and high density phenomena, methods for controlling high neutron fluxes, and new machining techniques. These technologies can already be applied in the areas of advanced transportation using magnetic levitation, space travel using nuclear propulsion, advances in medical diagnostic tools, astrophysical research, and the development of human interfaces to high speed computing equipment.

But in many ways the most profound "spinoff" of this fusion research effort has been, and will continue to be, the national defense impact of this research in high energy density physics. Although there is no fusion machine that can function as a weapon, the physical laws governing the bizarre states of matter characteristic of the fusion process are the same that must be mastered for the weapons and military technologies of the 1980s. We mention the following areas as especially prominent:

(1) The development of nuclear explosives. Little noted is the tremendous potential for the peaceful use of small, nearly fallout-free nuclear explosives for civilian purposes. Such devices have been demonstrated with yields as small as 500 tons of TNT and negligible uncontrolled radiation.

(2) Advanced propulsion systems. The need for advanced propulsion systems of the nuclear or fusion type has long been recognized and the magnetic technologies required are the basis of fusion research.

(3) Directed energy beam weapons. The development of these defensive weapons for the mission of antiballistic missile defense is regarded by many analysts as the most important task of military science in this decade. Such research is integrally intertwined with fusion research. The development of appropriate pulsed power sources, materials for beam production, understanding beam propagation, laser driver technologies, and

tailoring of energy on target are all critical questions that are attacked as part of a broad-based fusion program. It is instructive to note that the Soviet progress in beam weapons has been entirely dependent on their fusion program, and their present advanced state in weapons development relative to the United States is a result of their very broad-based fusion effort.

AN ADVANCED TECHNOLOGY ALTERNATIVE

The Fusion Energy Foundation believes that it is impossible to discuss the fusion budget adequately without situating these expenditures in the entire energy and research budget of the nation. Therefore, we have proposed a four-part energy and science policy to address the larger questions of energy, technological development, world economic recovery, and scientific progress.

(1) A near-term, aggressive program for nuclear power construction. Specifically, we propose the construction of 150 new nuclear plants during this decade. This represents a doubling of present construction plans and would, according to our econometric studies, save more in the cost of energy and economic multiplier effects than the plant construction cost involved. This program would require the federal funding of several crucial new energy technologies, specifically the high-temperature gas reactor and advanced fossil fuel technologies like magnetohydrodynamics.

(2) A broad-based, advanced nuclear energy research program, based on the breeder reactor and a broadened basic nuclear science program.

(3) A fusion program based on the funding levels set forth in the Magnetic Fusion Energy Engineering Act of 1980. This funding would continue a large scientific research effort, but initiate a full-scale engineering track of the fusion research effort, leading to an engineering prototype by 1990 and commercial fusion by the year 2000. This admittedly aggressive schedule is slower than the Japanese program for fusion energy development, and the proposed U.S. fusion budget presented by the Office of Management and Budget is less than the Japanese budget for fusion development!

We further propose that the laser fusion program, traditionally included under the Department of Energy's Office of Military Applications, be included in an Office of Fusion Energy and be rapidly expanded.

(4) The initiation of a national program for the development of directed energy beam weapons for ballistic missile defense. The funding of such a research and development program, under the auspices of either the Department of Defense or the Department of Energy, would

produce what Dr. Edward Teller called "the most important development in strategic warfare since the ICBM." Its military importance, however, is overshadowed, we believe, by its impact on the civilian economy, fusion research, space exploration, and almost every area of advanced scientific research.

NOTES

1. Lyndon H. LaRouche, Jr., "Economics and Population," The Campaigner (New York), October 1980.
2. Steven Bardwell, "Overturning Equilibrium Economics: The physical laws of economic development," Fusion (New York), June 1981.
3. Glenn T. Seaborg and William R. Corliss, Man and Atom: Shaping a new world through nuclear technology (New York: Dutton, 1971).
4. The Economic Impact of NASA R & D Spending, Michael K. Evans, Chase Econometrics Associates, Inc. NASA Report CR-144352-3 (1973).
5. Fremont Felix, "Our Top Priority: Expanded electrification will substantially reduce oil use, while propelling economic recovery," Gibbs and Hill report delivered at the Economy, Energy, and Electricity Conference, Toronto, Canada, 1980.

Appendix A

PROGRAM FOR ACCELERATED NUCLEAR POWER CONSTRUCTION

The Fusion Energy Foundation has called for construction of 150 gigawatts of nuclear power as the "driver" of a depression recovery program for our country in the 1980s. This program is based on an economic impact analysis developed by the Foundation. A conservative estimate shows that this recovery program will save the nation approximately $150 billion dollars over and above the construction costs of the nuclear plants required.

The program for 150 gigawatts of new nuclear generating capacity by 1990--100 GWe by 1987--roughly involves doubling the utilities' construction plans as of mid-1981 to meet the requirements of both recovery from the depression and sustained economic growth. The utilities then planned to build approximately 90 GW nuclear by 1987. Since then--because of cancellations brought on by useless regulation and the usurious high-interest rate policy of the Federal Reserve System, this figure has dropped to 83 GW in only six months time.

Utilities have been starved of the credit needed to build new capacity by the Fed's policies. In 1980, the year of the most recent complete figures, they raised on $37 billion of the $45 billion required by their own, highly conservative calculations. The nuclear industry and our nation's utilities need low-interest credit to become a driver for economic growth. We cannot let the Federal Reserve subject them to the same interest rates that are applicable to gambling casinos.

For $225 billion over the 1980s, with a rollback of nuclear regulatory practices inspired by opponents of economic growth, our nation can build 150 gigawatts nuclear and base our economic growth on productive investment again.

The construction program alone will create some 1,000,000 skilled jobs for the course of the decade, lowering the national unemployment rate by at least 1 percent. As President Reagan has pointed out, every such 1 percent reduction in unemployment saves our national treasury $25 billion per year. This alone will save the nation construction costs for the needed 150 gigawatts nuclear between now and the end of 1990.

In addition, bringing these plants on line throughout the 1980s--replacing far more expensive oil or coal-fired power with nuclear--will save power consumers (industry, consumers, and government) at least $100 billion by 1987, the first phase of the program, for a total of $150 billion by the end of 1990.

A vigorous nuclear power construction program--costing $225 billion--will save $375 billion in direct benefits of reduced unemployment compensation, increased tax revenues, and reduced costs for higher quality electricity. This estimate does not include savings derived from millions of new jobs created as these plants come on line.

Appendix B

PROPOSED NUCLEAR FISSION BUDGET

The budget proposal below, which calls for federal spending of $21 billion on advanced fission technology development, will solve existing problems facing the nuclear energy source our nation desperately needs before these problems become acute. With the proper, rapid allocation of funds, we can close the nuclear fuel cycle by the end of the decade. Budget items 3, 4, 5, and 6 are devoted to this effort.

However, the industrial process heat applications of the high temperature gas reactor (HTGR) show that advanced fission systems demand funding appropriate to the enormous economic benefits they will yield.

NUCLEAR FISSION BUDGET (in millions of 1982 dollars)

Category	Reagan 1982 Budget	1982	1983	1990	Total
1. Conventional Reactors	69.5	70	75	10	420
2. TMI Cleanup	--	75	100	--	500
3. Commercial Waste Management	240.3	260	300	75	1,810
4. Spent Fuel Storage	7.3	7.3	10	5	152
5. Breeder Reactors	736.5	750	800	500	6,325
6. Fuel Reprocessing	--	250	250	50	1,350
7. High Temperature Gas Reactor	--	250	300	800	5,250
8. Other Advanced Fission Systems	38	38	45	40	408
9. Uranium Supply and Enrichment Activities	194.8	210	225	250	2,460
10. Basic Nuclear Science	160.6	175	190	325	2,265
TOTAL	1,447	2,085	2,295	2,055	20,940

Appendix C

PROPOSED NUCLEAR FUSION BUDGET

The following are projected budgets for fusion research and development that would lead to the realization of commercial fusion by the year 2000, the goal set by the Magnetic Fusion Energy Engineering Act of 1980.

The Magnetic Fusion Program. In order to balance the overall magnetic fusion effort, given the large Engineering Test Facility program element based on the tokamak, a vigorous mirror and alternate concepts program are both brought to the point where commercial demonstration plant construction would begin in 1991. These would include the Mirror Fusion Test Facility upgraded to the full reactor-grade plasma tandem configuration, the MFTF-B; a Mirror Reactor Test Facility, MRTF; an Alternate Concepts Physics Test Facility, together with several Alternative Concepts Proof-of-Principle experiments, ACPOP; and a reversed field pinch proof-of-principle experiment, which would probably duplicate the MFTF-B in attaining reactor grade plasmas.

The primary focus of the accelerated magnetic fusion program would necessarily be technology development. However, this technology would be universally applicable to all magnetic confinement approaches and many aspects of inertial confinement, so that the first commercial plants could be based on alternative concepts to the tokamak.

Inertial Fusion Program. In the inertial fusion program, existing facilities at the major national labs would be completed as rapidly as possible. By the mid-1980s, the Livermore Nova glass laser system and the Sandia Particle Beam Fusion Accelerators (light ion beams) will have demonstrated scientific breakeven for ICF. But in order to demonstrate high gain pellet targets needed for commercial ICF reactors, a megajoule Super Nova glass laser system will be needed by the late 1980s. While this type of laser is probably not capable of meeting the requirements of a commercial reactor, it offers the nearest term and most flexible technology for demonstrating high gain targets.

Simultaneously, the Los Alamos carbon dioxide gas laser system and a krypton flouride(KrF) laser system would each be completed on a scale sufficient for breakeven studies. These more reactor relevant drivers could prove capable of going all the way. But the chief base for an Engineering Test Facility will be that of the well known technology of heavy ion beam accelerators.

BUDGET FOR ACCELERATED MAGNETIC FUSION PROGRAM (in millions of 1982 $)

	1983	1984	1990	Total
1. Confinement Systems Division	42	54	--	198
2. Basic Operations Budget	180	180	180	1,440
3. Planning and Projects Division	145	130	80	995
4. Engineering Test Facility PACE	--	240	--	1,320
5. Engineering Prototype Reactor PACE	15	15	240	580
6. Other	278	529	800	4,725
TOTAL	660	1,150	1,300	9,218

BUDGET FOR ACCELERATED CONFINEMENT FUSION PROGRAM (millions of 1982 $)

	1983	1984	1990	Total
1. Operations	150	200	300	1,750
2. Nova Laser	70	50	--	120
3. Super Nova Laser	40	80	--	380
4. Carbon Dioxide Laser	40	80	--	340
5. Other	160	300	800	4,240
TOTAL	460	710	1,100	6,830

The promise of fusion: What and when?

The tantalizing attraction of fusion is unlimited availability of energy resources. Experts claim the physical principles have been established and the time has come to move from research intc engineering

By Stephen O Dean, Fusion Power Associates

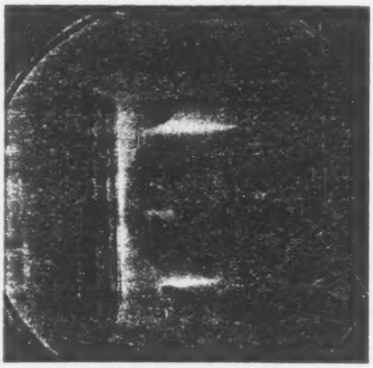
In 1960, when putting a man on the moon was made a high political priority by then-President Kennedy, the nation marshalled the necessary financial and human resources to take the project out of the laboratory and make it a reality. The result is history.

Today, the problem of dwindling energy resources certainly merits the same order of concern. Experts closest to the fusion concept say it is time to express the same national resolve. They seem to agree that this is the time to bring utilities, architect/engineers, and manufacturers into the picture, so that the engineering concepts can be used to develop machinery they can live with.

What makes the time propitious? Both the need and the state of the art. At current production levels, our known oil reserves are being depleted at the alarming rate of 10% per year. Zero growth may be forced on our economy before very long if political considerations continue to dictate sharply reduced reliance on imports and the problems with expanding other energy resources continue.

As for the state of the art, the key fusion parameters—plasma temperature, density, and confinement time—have all been achieved separately in laboratory tokamak devices. Researchers are convinced that everything will come together in Princeton University's Tokamak Fusion Test Reactor (TFTR) to produce the first fusion reaction in which more energy is released than is consumed. TFTR is scheduled for completion later this year. Experiments have shown that the concept can be scaled up with confidence, and that several problems that had been anticipated will be resolved.

As a virtually inexhaustible energy source, fusion offers a long-range economic advantage. Being insensitive to the shortage-induced price rises experienced by petroleum, gas, coal, and uranium, it will become increasingly competitive with other energy sources.



The glow of fusion as seen through a viewing port in a Princeton University tokamak

Recent studies conclude that fusion reactors of 500 to 1000 MW will be feasible. This size range is optimum in terms of both capital requirements and system vulnerability to outages. Once considered difficult to attain with the fusion concept, this range has been a conscious design goal even in the basic research phase of the program.

Fusion is expected to reduce the environmental and siting problems faced by utilities. Radioactive waste will consist primarily of structural members, in which neutron bombardment has produced isotopes with short half-lives, and tritium, a part of the fuel-cycle product with low radiotoxicity and short half-life. The radioactive structural members will require storage for much shorter periods of time than the waste products of fission plants—decades compared to hundreds of years.

Criticality accidents are not possible in fusion reactors, and the absence of afterheat in the fusion core makes coolant-flow disruptions a much less serious problem than in a nuclear-fission plant. Since the deuterium/tritium-fusion fuel cycle will be almost entirely self-contained in the reactor, the usual fuel services and their potential environmental impact will be eliminated. Unlike fossil-fuel plants, there will be no problem with chemical or particulate emissions or with ash disposal. If fusion technology advances to nontritium fuel cycles, there will be almost no radioactive byproducts, and the production of energy will truly become environmentally benign.

In terms of human history, the international political significance of totally eliminating our dependence on limited resources for energy production may be even greater than environmental issues. Clearly, if fusion can replace oil, natural gas, coal, and uranium soon enough,

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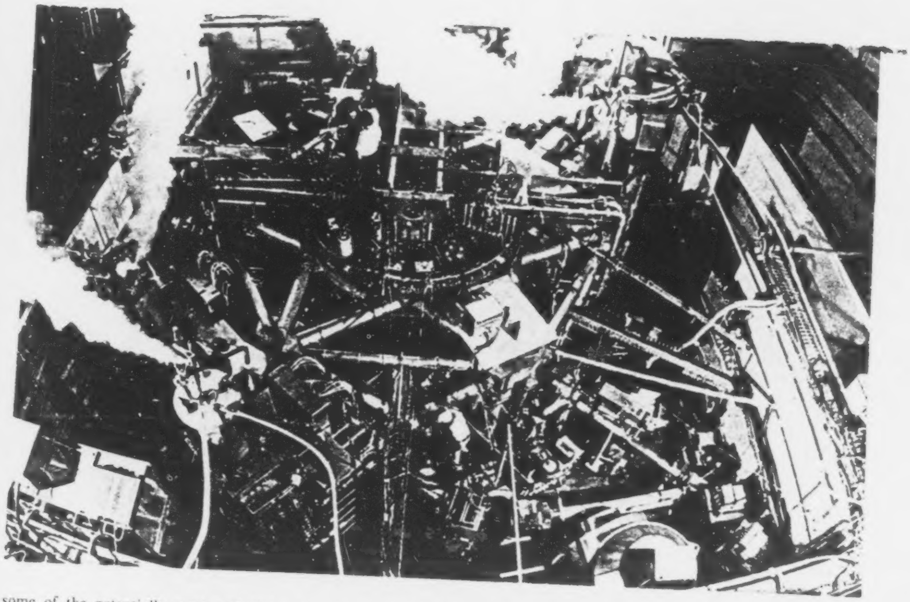


some of the potentially most explosive international tensions could be defused.

Fusion-technology options

Despite having similar names, fusion and fission are alike only in that both are based on subatomic physical reactions, just as both a steam engine and a rocket engine rely on Newtonian physics and the laws of combustion.

Where fission splits nuclei of atoms into smaller components, fusion releases energy by fusing two nuclei together. The fusion reaction occurs when nuclei of deuterium (the hydrogen isotope having one neutron and one proton in the nucleus) and tritium (the isotope with one proton and two neutrons) combine to produce a helium nucleus. Since the helium nucleus has two protons and two neutrons, one neutron is excess. It is released in the reaction, and much of the energy released is associated with it.

Fusion is the reaction of the sun. The sun converts 657-million tons of hydrogen every second into 652.5-million tons of helium. The heat and light of the entire solar system, extending 5-billion miles into space, is produced by the conversion of that 4.5-million tons every second of solar mass into energy.

The sun can accomplish this at a comparatively low temperature. The tremendous gravitational forces of the great mass of the sun compress and heat its substance to about 15-million C at a high enough pressure for the reaction to take place. It is not possible to create on earth a pressure equivalent to the gravitational force of the sun. The reaction temperature, therefore, must be increased to compensate for the lower pressures involved. Thus, fuel temperature must be raised to about 100-million C—six times the temperature of the interior of the sun—to effect fusion!

The two isotopes, deuterium and tritium, are readily obtained. Deuterium is abundant in sea water and can be recovered fairly easily. Although tritium does not occur naturally, it can be obtained from lithium, which is abundant. In practice, tritium will be made in the reactor itself. A deuterium/tritium fuel cycle will most likely be chosen for the first-generation fusion reactors, because this reaction has the lowest temperature threshold and releases the most energy.

In a fusion reactor, once the fuel is at a high enough temperature, the basic problem is to confine it at that temperature long enough to release more fusion energy than was spent getting it hot and keeping it confined. This is termed the breakeven point, and represents the first milestone. The next one is the ignition point, where the reaction becomes self-sustaining and the external energy source can be removed.

Magnetic confinement leads

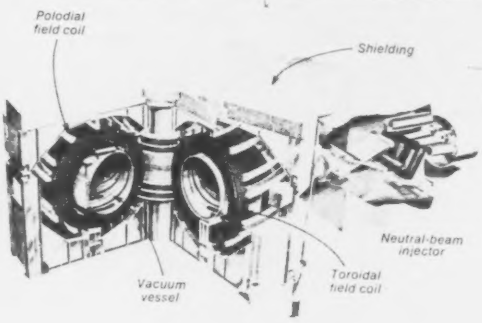
Fusion devices are classified primarily according to the method used for containing the plasma: magnetic or inertial. Major research successes in magnetic confinement have been achieved in recent years. The lead concept is the tokamak, a Russian acronym for "toroidal chamber with magnetic coils." It describes a doughnut-shaped device in which magnetic-field lines, twisting around the torus (doughnut), close on themselves to confine the plasma (Fig 1). Because the particles of the plasma are charged, they resist crossing the magnetic lines of force.

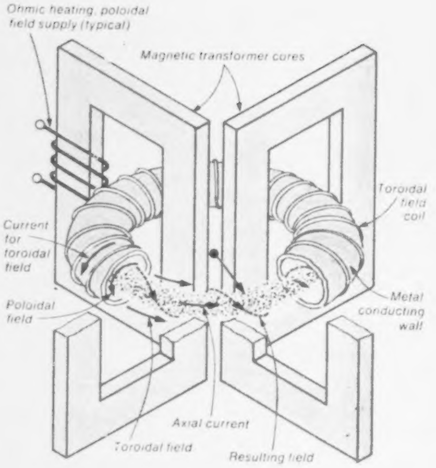
First fusion breakeven is expected within the next two or three years in the TFTR. It cannot be predicted with certainty that the tokamak will ultimately prove to be the best machine for economic production of electricity, but for a variety of reasons, it is further along than other concepts and ready for engineering development.

Tokamak projects so far have concentrated on one parameter, either plasma density, temperature, or confinement time. They have been designed to push the parameter to its critical value, but usually at the expense of the other parameters. Doublet III at General Atomic Co—the world's largest operating tokamak—was designed to develop high values for all three parameters simultaneously, using a hydrogen plasma (Fig 4). TFTR's goal is to bring all the parameters to the breakeven point with a deuterium/tritium plasma. Note that a plasma is a unique form of a gas: At the extreme temperatures involved, the electrons normally surrounding the atomic nuclei are torn away, forming a fourth state of matter.

Containment of the extremely hot plasma long enough to enable sufficient fusion energy to be released is the basic problem characterizing the concept. A popular misconception is that the magnetic field is used to contain the plasma.

1. Magnetic confinement of plasma is the most advanced fusion concept to date. Sketches represent hardware (below) and operational concept (right) embodied in the favored geometry—tokamak, a Russian acronym for toroidal plasma chamber with magnetic coils. Photo at left is an overview of Princeton Large Torus (PLT), an experimental device that has achieved 60-80 million C temperatures. Tokamak Fusion Test Reactor (TFTR), below, scheduled for completion this year, is expected to reach energy breakeven at 100-million C by the middle of this decade




Ohmic heating, poloidal field supply (typical)
Magnetic transformer cores
Toroidal field coil
Current for toroidal field
Poloidal field
Metal conducting wall
Axial current
Toroidal field
Resulting field

since any ordinary container would obviously vaporize at a temperature six times hotter than the sun's interior. Actually, the plasma's density is so low (1/100,000th the density of air at sea level) that melting of the vessel would not be a problem. So sparse a population of particles would not heat up the metal containment beyond its capabilities, even at that temperature.

More correctly, the fundamental confinement problem is to avoid the loss of heat. Contacts with the first wall—the structure immediately surrounding the magnetically confined plasma—would cause an unacceptable loss of heat, making it impossible to get the plasma's temperature up to the level required.

One of the most dramatic scientific/research stories of the past decade has been the inching up of plasma temperatures toward the critical value (Fig 2). The goal for a reactor is a minimum of 45-million C for breakeven, and 80-100-million C for an economical reactor. The Ormak device, developed at Oak Ridge National Laboratory (ORNL), achieved 20-million C in 1975. The Princeton Large Torus (PLT) recorded 60-million C in 1978, and 80-million in 1980. The latter value was also achieved by another Princeton device—the Poloidal Divertor Experiment (PDX)—in 1981. The TFTR is expected to reach temperatures up to 100-million C by the mid-1980s.

The earliest temperature milestones were achieved in the 1960s solely by ohmic heating. In this method, plasma offers resistance to the current induced in it by the magnetic field. However, as in familiar ohmic-heating devices such as light bulbs and electric toasters, the hotter the plasma gets, the less resistance it offers. This makes it difficult to heat the plasma beyond a few tens of millions of degrees by this means alone.

In the 1970s, a new auxiliary heat source became practical. It enabled injection of intense beams of energetic hydrogen atoms into a plasma. Researchers at ORNL and at the Lawrence Berkeley Laboratory (LBL) developed high-current ion sources capable of generating neutral beams in the 100-kW range at ion energies of tens of kilovolts. Addition of these to the PLT and other tokamaks has made possible the temperature increase noted above.

Confinement of sufficient fuel for the minimum specified time is the other fusion requirement. This is measured by the Lawson number, the product of energy confinement time in seconds and plasma density in particles per cubic centimeter. The higher the density of the plasma, the shorter the time that it must be sustained to yield the desired energy release; the fusion reaction rate is faster at higher densities.

The minimum Lawson number for breakeven is 10^{13} sec cm^{-3}. It applies to what is known as the two-component mode, where the deuterium and the tritium are at different temperatures—a condition yielding the lowest threshold. This value of the Lawson number was first achieved at MIT in 1975, in the Alcator A experiment; it went on to achieve 3×10^{13} sec cm^{-3} in the Frascati tokamak in Italy, in 1981. A new MIT tokamak, Alcator C, is now operating with a goal of exceeding the thermal-mode (with the two components at the same temperature) breakeven threshold of 6×10^{13} sec cm^{-3}.

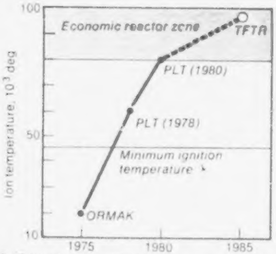
Thus, Lawson numbers now attainable are within the breakeven range. The TFTR should achieve the simultaneous conditions of temperature and Lawson number required for a fusion reaction and, for the first time, more energy will be produced than was invested (Fig 3).

Early in the development of the tokomak concept, many researchers had feared that temperatures and confinement times successfully attained in comparatively small experiments could not be maintained predictably when the plasma was scaled up to actual reactor conditions. In 1978, however, in a crucial test at the PLT—a scaled-up tokamak—the scaling laws that had been developed were verified at temperatures up to 70-million C. No apparent deterioration of confinement or instability was evident.

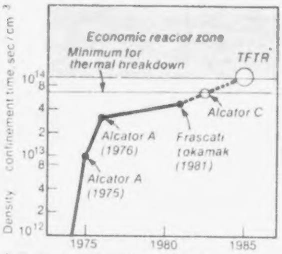
Magnetic mirror advances

Another magnetic-confinement concept is the linear magnetic mirror. In its simplest form, it is an open-ended tube of magnetic-force lines (Fig 6). Stronger magnetic fields exist at the ends, to reflect the plasma particles back into the interior where the magnetic field is weakest.

For commercial applications, the mirror concept has two attractive features: easier access for maintenance, and operation in a steady state rather than in



2. How plasma temperatures have inched up toward economical operating range



3. Product of density and confinement time has also approached breakeven

pulses (like the tokamak). Scaling up, moreover, would present fewer problems. The primary hurdle here is to minimize losses of charged particles at the ends of the device. The physics involved has not been developed sufficiently to define reliable reactor concepts.

Higher values of temperature and density numbers have been achieved in magnetic mirrors than in tokamaks. But the highest Lawson number achieved is only about one one-hundredth of that for a tokamak. The 2X-IIB at Lawrence Livermore National Laboratory (LLNL) achieved an ion temperature of 130-million C (in 1975), compared with 70-million C for the PLT tokamak.

Lawrence Livermore has been assigned responsibility for developing the magnetic-mirror approach. The MFTF-B, now being built there, will operate in 1984. It is a large scaling experiment to test the mirror physics beyond the plasma parameters achievable in existing facilities.

Variations. There are several other toroidal configurations for magnetic confinement. A different form of magnetic-mirror device is ORNL's Elmo Bumpy Torus. It features a toroidal geometry as a method for feeding end losses back into the reactor. Another toroidal device—not based on the magnetic mirror—is General Atomic's Ohmic Heating Toroidal Experiment (Fig 5), primarily a joint venture with Phillips Petroleum Co. It uses a helical winding around the torus to achieve more efficient energy utilization, hence a more compact reactor.

Inertial confinement

Two steps are involved in the inertial-confinement concept: (1) Fusion reactions are initiated in the center of a small, super-dense fuel pellet, and (2) these reactions propagate outward for as long as the pellet remains intact. Just how long this lasts is determined by the size and temperature of the pellet. At the end, the pellet blows apart and the energy output ceases (Fig 8).

Small pellets—typically about a millimeter in diameter—are used because larger pellets would require a greater input energy, and because the terminating microexplosion must be contained. Typically, these small pellets have inertial times of the order of 10^{-10} seconds before disintegration.

The amount of energy released during this time depends on the pellet's compressed density, and varies with other specifics of a given pellet. Calculations show that a pellet must be compressed to at least 700 times the density of water (as many as 3000 times in some cases) for a significant energy gain to be realized from an input of 1 MJ.

Achieving high compression density with low fuel temperature in the core is the primary measure of progress in inertial-confinement fusion. An incident laser or energetic-particle beam introduces the input energy at the surface of the pellet, imploding it (Fig 8). During this compression process, it is important that the temperature of the fuel at the center (core) remain sufficiently low until the last possible moment. Otherwise, the core will exert a backpressure, inhibiting the compression and, therefore, increasing the energy input required.

Scientists at LLNL have succeeded in compressing fusion fuel pellets to more than 100 times the density of liquid hydrogen. Although this still falls about 90% short of the requirements, it is a compression level unheard of only a few years ago.

Intensive investigation is being conducted into the wavelength dependence of energy absorption, and its relation to preheating of the pellet core. Experiments now under way at a number of laboratories in the US and Europe indicate that, at shorter wavelengths, the pellet absorbs laser energy more efficiently, and the number and energy of hot electrons are smaller. (Note: Hot electrons are the cause of preheat.) Thus, energy-input amounts soon to be available should be adequate to achieve the compression levels required for ignition.

Suitable lasers, however, are not yet available. They must have the optimum combination of efficiency (6-15%), energy (1-5 MJ), and multiple-pulse capability (1-10 Hz). At short wavelengths, candidates under active investigation include krypton fluoride, the free-electron laser, and new solid-state lasers (other than glass) capable of frequency multiplication.

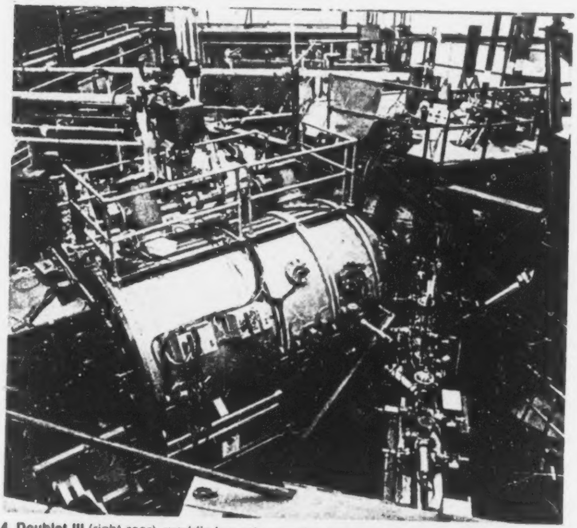
For inertial confinement, ignition is expected to occur on an energy absorption of about 1 MJ. The Particle Beam Fusion Accelerator (PBFA-I) recently completed at Sandia National Laboratories, rated at 1 MJ, has already operated at up to 840 kJ on its first test runs, without energy focus on the target (Fig 7). By the mid-1980s, researchers there hope to focus a few hundred kilojoules on target from PBFA-I, and more than 1 MJ from an upgraded version, PBFA-II. An upgraded laser at LLNL also aims at achieving ignition by the mid-1980s. (For completeness, note that heavy-ion beams are also considered a potential fusion driver. The R&D program in this area, however, has not progressed very far.)

The new lasers (krypton fluoride and free-electron lasers) have not been developed sufficiently for use in critical tests of inertial-confinement physics. The only ones suitable for tests are the existing lasers—neodymium-doped glass (1-micron wavelength) and carbon dioxide (10 microns).

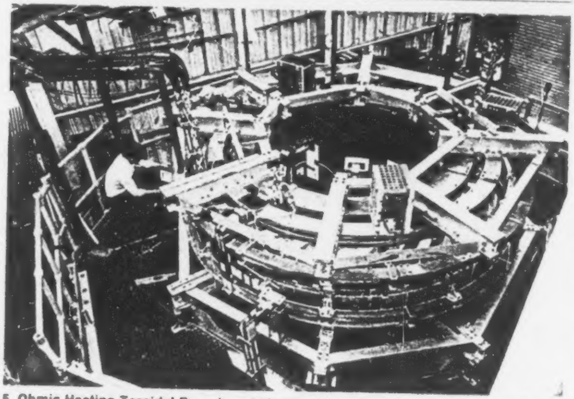
The former have a low energy-conversion efficiency, and cannot be fired rapidly—only once in 5-10 minutes, as opposed to 1-10/sec. The carbon dioxide design converts electrical power into laser light at fairly high efficiency, and could be developed to pulse at the high rate that is needed for a commercial reactor. But, because the emission wavelength is long, it does not couple energy to the pellet very efficiently.

At first glance, the laser would appear to be the best choice of driver, because its energy can be focused accurately on the target from distances long enough (more than 100 meters) to remove the high-technology components from the chamber where the reaction takes place. However, rough cost estimates indicate that the kind of lasers needed will have to be less expensive than today's lasers if they are to provide economical commercial power.

Light-ion beams are relatively low-cost and efficient, and appear likely to achieve the desired power and repetition rate. But accurate, long-distance focusing has not yet been demonstrated. Heavy-ion beams, the least-developed driver, appear to have good absorption and focusability, and high efficiency. On



4. Doublet III (right rear), world's largest operating tokamak, allows for D-shape plasma cross section, rather than circular. Neutral-beam injector is in foreground



5. Ohmic Heating Toroidal Experiment (OHTE), joint venture of General Atomic Co and Phillips Petroleum Co, aims for better energy utilization, more compact reactor

the other hand, they may necessitate the use of large machines involving intolerable capital investment.

The road to commercialization

The next step for the magnetic-fusion concept on the way to economical commercial power may be the Fusion Engineering Device (FED) in this country, or the International Tokamak Reactor (INTOR) internationally. FED is the prototype to be built by 1990 at the Center for Fusion Engineering, as mandated by the Magnetic Fusion Energy Engineering Act of 1980 (PL 96-386). It will not only bring together the technology developed to date and scale it up toward a commercial size, but it will include fueling, maintenance, and other practical engineering aspects. Most important, it will feature the direct involvement of industry—the utilities, manufacturers, and engineering companies that will actually build and use future commercial fusion-power stations.

Among the engineering questions to be faced in the construction of this device are the materials for the first wall (the inside wall of the vessel); materials for the blanket; design of blankets for heat transfer and tritium breeding; technology for superconducting coils, refueling and ash-removal systems, and auxiliary heating systems; tritium processing and handling techniques; remote-maintenance methods, and the reactor-control system.

John Gilieland of General Atomic Co is head of the FED-management team. As he sees it, a major goal of the FED will be to demonstrate the tritium fuel cycle in a practical setting. This includes finding answers to such questions as how to extract the tritium without losing any and without suffering mishaps, how to perform maintenance and repairs by remote control, and how to accomplish periodic replacement of the radioactive walls of the reactor.

The configuration assumed for a working commercial fusion reactor is a plasma surrounded by a blanket of lithium. The lithium nuclei will absorb the fusion neutrons and convert to tritium in the process, closing the fuel cycle within the reactor itself. Concern about the first-wall materials has two aspects: impurities entering the plasma from sputtering of the wall by energetic charged particles, and the maintenance and radioactive-waste problems created by activation of the wall material.

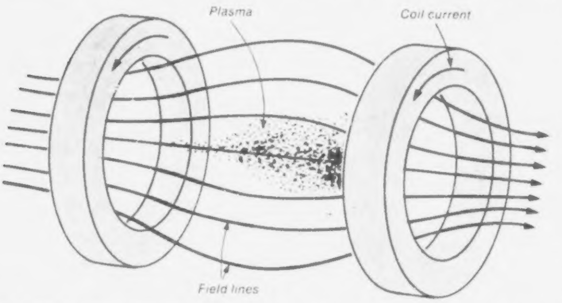
Impurities present in the plasma cause radioactive heat loss from the center of the plasma, making it difficult to achieve the temperature and confinement parameters necessary for ignition. Sputtering occurs where the outer magnetic-field lines encounter solid structural materials. One solution to the problem is use of "limiters." These are made of a heat-resistant material, such as tungsten or molybdenum, in the form of heavy bars; they are strategically located to limit the amount of sputtering.

Researchers have also experimented with the use of graphite as the limiter material. It sputters more readily than tungsten, but the resulting impurities—carbon ions—are far less damaging to the energy balance of the plasma, because carbon atoms become fully ionized in the plasma's interior. The heat is thus radiated mainly from the cold outer edge—a less-critical region, since most of the fusion reaction occurs at the center.

Although radioactive wastes from a fusion reactor are less than those generated in conventional nuclear plants, the radioactivity has two forms: tritium gas and activated structural members.

Tritium is a low-radiotoxicity, short-half-life isotope. Its maximum allowable concentration is among the highest for any radioactive material. It is excreted rapidly from the body, and cannot be biologically concentrated in the environment, in food chains, or in man. Since it decays with a half-life of 12.3 years to harmless helium, its health hazard is not very long-term, compared to some products of nuclear fission. However, there will be substantial quantities of it (an estimated 1-10 kg) and, being a gas, it is hard to contain. It readily permeates most common structural materials.

The other radioactivity problem arises from the fact that the deuterium/tritium reaction releases most of its energy in the form of high-energy neutrons. These pass unimpeded across the magnetic-confinement fields; some penetrate the walls of the vacuum chamber, and others are absorbed by the chamber walls. They induce radioactivity in the structure and can cause sufficient damage to require periodic replacement of the first wall. Because the structure becomes radioactive, any required replacement must be done with remote-handling techniques.



6. Magnetic-mirror concept is based on open-ended tubular array of magnetic force lines. Stronger fields are applied at ends to reflect plasma back into tube's interior

Despite the high temperatures within the plasma (around 100-million C), temperatures at the first wall can be kept at acceptable levels—300-600C—with various cooling techniques. But damage through swelling and embrittlement, and surface erosion through sputtering, will make it necessary to replace the first wall regularly, perhaps as often as every five years. Development of materials that are more radiation-resistant, a part of the assignment for the FED, could extend the periods between replacements. Selection of operating temperatures, design configurations, and protective features will also be factors in the longevity of first walls.

The ultimate reactor size will be partly determined by engineering work to be done on making the first wall radiation-resistant. In reference designs, the neutron energy-flux limits for the first wall have been set at about 2 MW/sq m of wall. Aggressive development work on materials should permit an increase in this limit. As an example, it has been found that adding titanium to stainless steel greatly improves the ductility of irradiated material at high neutron exposures and high temperatures.

Development of better first-wall materials will also enhance plant availability, a key element in utility acceptance of the concept. Frequent replacement of the first wall, combined with limited personnel access, could require time-consuming remote maintenance. Emphasis in current design studies has therefore been placed on decreasing component size, increasing accessibility, and improving manned access through shielding. Engineers working with these designs are confident that the technical problems can be solved, and that plant-availability factors no worse than those of today's nuclear-fission reactors, and consistent with utility economics, can be achieved by the time fusion is ready for commercial use.

Although problems with first-wall life and structure irradiation are common to all fusion-reactor concepts, component accessibility varies. With its doughnut-shaped reaction chamber, the tokamak has more access problems than other concepts of both inertial confinement and magnetic mirrors.

The radioactive-waste problem encountered in fusion-energy generation is created by activated structural members that have deteriorated to the point where they must be replaced. It differs from that encountered in fission energy in several important ways. Waste products of fusion are generally nonvolatile. Bound up in the structural materials, they are extremely difficult to release to the environment, even in accidents. Moreover, the types and amounts generated can be minimized by design, engineering, and materials selection. This is not true of fission radwastes to the same degree.

Another engineering question to be addressed is construction of superconducting magnetic coils. Although the technology for building superconducting magnets is essentially in place, those required for fusion-power reactors will be larger than any built to date. R&D in this direction is in progress at Lawrence Livermore and ORNL, as well as Westinghouse Electric Co, General Electric Co, and General Dynamics Corp.

Refueling methods for commercial plants will be developed and tested during the FED project. At the present laboratory level, where fusion reactors are designed to operate for very short times, refueling has not been necessary. Ultimately, it may require nothing more than surrounding the plasma with a neutral-gas blanket that feeds gaseous deuterium/tritium at the plasma edge. However, if the fuel must be injected into the center of the plasma, the problem will be more difficult. One technique proposed has been the very-high-speed injection of frozen deuterium/tritium pellets the size of sand grains into the plasma.

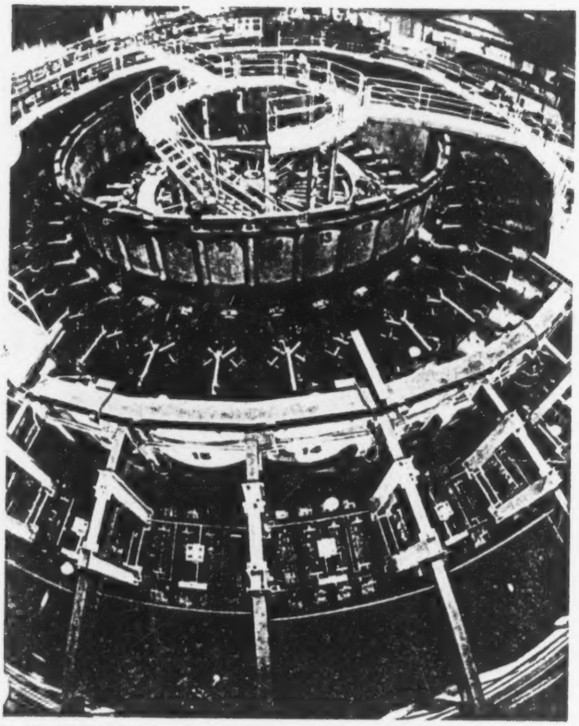
Operation of tokamak is cyclic. The current is induced in the plasma by a transformer positioned inside the torus. Limitations of the transformer flux swing make the discharge pulse cyclic. While the period when energy is not being produced is a matter of milliseconds in today's laboratory machines, it could be much longer in large commercial devices—perhaps several hours.

Energy-storage systems may be required to rectify these swings to produce a steady electric output. Complexity of the storage systems will depend on the length of the burn period, the length of the recovery period between burns, and the design of the reactor. Other fusion concepts, such as the magnetic mirror and the Elmo Bumpy Torus, deliver power steadily, rather than in pulses. Recognizing these disadvantages, fusion researchers have been devoting some effort to driving the current in a tokamak continuously.

Conceptual designs

Taking existing scientific knowledge and combining it with what is known about the kind of commercial fusion reactor that utilities will need, a design team produced a conceptual reactor design. The design is hypothetical and will never be built as such, but it is a key step in focusing future engineering efforts.

Called Starfire, the design is the work of a team at the Argonne National Laboratory, with major input provided by McDonnell Douglas Astronautics Co, General Atomic Co, and the Ralph M Parsons Co. A similar design, called MARS (Mirror Advanced Reactor System), is under development at LLNP,



7. Particle Beam Fusion Accelerator (PBFA) embodies inertial plasma-confinement concept. Plasma-ignition capability appears to be within reach

with TRW, General Dynamics Corp, Ebasco Services, and Science Applications Inc participating.

Primary criteria for making Starfire commercially attractive were economics, safety, and environmental impact. The designers also worked on reactor maintainability and plant availability, selecting design features that could reduce the frequency of failures and shorten replacement times. Systems were incorporated to reduce the tritium inventory and to keep the tritium contained within a series of barriers. Other design steps were taken to minimize the size of any potential tritium leaks. Remote maintenance was incorporated to reduce personnel exposure to radiation, and reactor materials were selected to allow recycling of all materials outside the blanket within 30 years.

To make it comparable to present generating units using other fuels, both in output and availability, the conceptual Starfire was designed to produce about 1200 MW in steady-state operation. Technologically, the steady-state mode (achieved by driving the reactor with radio-frequency power) constitutes the only radical departure from current experimental tokamak designs. Otherwise, Starfire represents a combination of the best options from previous designs, in terms of materials, blanket design, magnets, refrigeration, heat transfer, etc.

With the Starfire concept, downtime is minimized and reliability is improved by using "replace and remove" maintenance, in which failed components are replaced with spare parts and repaired. Redundant equipment is provided in areas where maintenance is more difficult. The shielding and the toroidal field-coil components comprising about 90% of the reactor's bulk are designed to last the plant's lifetime.

Particular attention in designing Starfire was given to maximizing utility compatibility, with regard not only to current practice but also to anticipated trends for future utility operation. Operating parameters for the design comprise base-load operation, a four-week scheduled maintenance shutdown each year, and a four-month outage every 10 years for turbine/generator overhaul and annealing of the toroidal coils. Combining these design features with the industry-average outages for balance-of-plant, the study projects a 75% availability for Starfire.

In extrapolating from what is now known about plasma physics and, in some cases, about actually designing equipment, the Starfire team has made valuable information available to future designers of fusion reactors.

Economic projections

The commercial-reactor design based on the Starfire concept costs an estimated $2000/kW (1980 dollars) and has a busbar-energy cost of 35 mills/kWh. There are obvious uncertainties in predicting the cost of energy for future fusion reactors. However, Charles C Baker, program director for Starfire at Argonne National Laboratory, claims that there appears to be no fundamental reason for fusion not to be economically competitive.

Ebasco has made projections comparing the economics of fusion with other electric-power sources. Such projections indicate that the levelized-busbar-power cost for the first 10 years of plant operation (1992-2002) would be about 134 mills/kWh for a fossil-fired plant burning eastern coal and 121 mills/kWh with western coal; the cost would have to be 112 mills/kWh to be competitive.

This translates into a capital investment no greater than $3374/kW escalated to initial operation at the end of 1991, or about one-third more than a nuclear plant capitalized at $2557/kW. Assumptions include tritium breeding in the fusion reactor, and fixed charges of 18.1% for coal-fired plants and 18.5% for light-water reactors (LWR) and fusion plants.

The fusion fuel cost is extremely low: 0.06 mills/kWh compared with 25 mills/kWh for LWRs and 63-78 mills/kWh for coal-fired plants. The 0.06 mills/kWh figure seems likely to be achieved within an order of magnitude, according to Ebasco. But even at 0.6 mills/kWh, the fuel cost would be low enough to provide the leeway needed for breakeven capital costs. And, as noted earlier, the fusion fuel cost would not be subject to the escalations applicable to exhaustible fuels.

The capital costs of fusion plants are expected to be slightly higher than those for nuclear-fission plants. The quantities of materials should be about the same, but a few special problems peculiar to fusion are anticipated. On the other hand, fewer licensing delays are anticipated during the construction stage.

Inputs from utilities are needed at an early stage if fusion plants are to be competitive. Among the factors considered essential by utility executives are the following:

- Safe and licensable technology.
- Cost and lead time comparable with or better than other generation technologies.
- Environmental impact no worse than that of coal or nuclear fission.
- Design simplicity to minimize probability of an accident and negative impacts on reliability.
- High plant availability.
- Instrumentation and controls matched to operator limitations.

Industry cooperation vital

There should be significant industry involvement in the Fusion Engineering Device. The Congressional Fusion Advisory Panel (Energy Research & Production Subcommittee, House Science & Technology Committee) recommends strongly that DOE immediately perform an in-depth study of organizational options for managing the Engineering Test Facility (ETF) project, and that it include major input from the existing fusion community—particularly from qualified industrial organizations.

The panel has urged that the management approach for the project ensure that "responsibility for the design and construction phases be placed in the hands of an organization or consortium that is experienced in the management and operational aspects associated with the construction of facilities of similar magnitude and complexity."

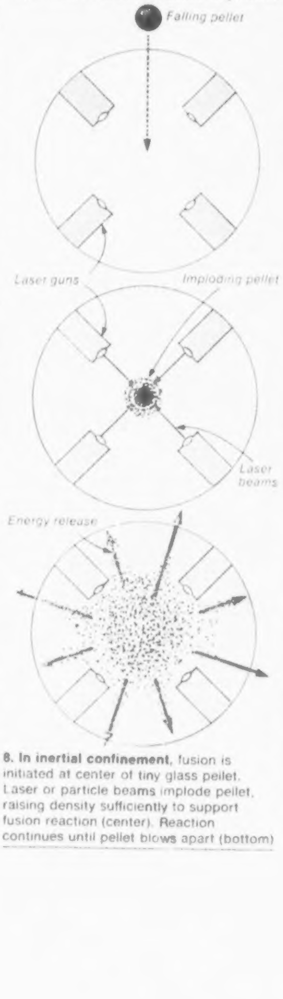
Although the ambitious ETF has been replaced by the somewhat more modest FED, there is no less need for intense industry involvement. The FED will be managed by the Center for Fusion Engineering (CFE). This is yet to be set up, but all indications are that it will include heavy participation of industry. Although it is too early for any industry action to finance fusion, DOE spokesmen have indicated that the time is ripe for corporations to begin determining how to acquire the capital necessary to build and operate fusion reactors.

Industry appears eager to join in. A typical attitude is expressed by Harold K Forsen, manager of Engineering & Materials for The Bechtel Group. Pointing out that CFE, as well as FED, will be responsible for managing development of technology, and of reactor systems and components, he urges government to develop a mechanism to include industry in the design criteria, and to select one organization, possibly an industrial contractor, to head CFE. His main concern is that the engineering and manufacture of fusion systems "may take longer and cost more than developing the science."

The prime mover behind passage of the Magnetic Fusion Energy Engineering Act was former Rep Mike McCormack (D-Wash). Pointing out that fusion "will provide adequate supplies of energy to allow upgrading of lifestyles and to promote world peace," he has cautioned that peace could be in jeopardy as nations increasingly grab for depleting stocks of fossil fuels.

McCormack contends that US energy requirements will increase dramatically by the year 2000, and calls for construction of 400 more nuclear-fission plants and a tripling of coal production by that time.

According to DOE's Energy Information Administration, at the production levels recorded in 1980, the US has 10 years of proven oil reserves. Another nine years are promised by "indicated" reserves (known to be producible with secondary-recovery techniques). The equivalent of a new Prudhoe Bay, therefore, would be needed every decade to continue present production capabilities into the next century.



8. In inertial confinement, fusion is initiated at center of tiny glass pellet. Laser or particle beams implode pellet, raising density sufficiently to support fusion reaction (center). Reaction continues until pellet blows apart (bottom)

For years, natural-gas production has outstripped discoveries of new reserves, although this trend may have been temporarily reversed by the vast discoveries that were made following price deregulation. Although the US has more than a quarter of the 786-billion tons of the world's known coal reserves (the Soviet Union and China each have about as much as we do), much of it is inaccessible with present technology or at present prices.

Both coal and nuclear power continue to face great political problems hampering their full use. Concern for the environment, health and safety—and, in the case of coal, labor stability—all will tend to keep us more dependent on oil than we would like to be, until a less-controversial energy source, such as fusion, is available.

Since the fuel for fusion plants is in virtually inexhaustible supply, fuel costs should be stable and low. The primary cost for a fusion central power station will be the capital investment. Until fusion becomes a widely used energy source, the costs of building the fusion machinery and plants, as with all goods, will rise with the cost of energy. Thus, although the use of fusion-produced power should ultimately stabilize energy costs, even in the face of dwindling mineral-fuel supplies, the level at which they are stabilized will depend on how soon fusion becomes commercial.

Fusion timetable. DOE has projected a timetable leading through construction of the ETF, starting in 1984 and operational by 1992; an experimental power reactor, to be begun in 1997 and operational by 2004; a demonstration plant, begun in 2005 and completed in 2015; and commercial plants actually constructed in the last part of that decade. The timetable is based on sequencing of R&D activities and the level of funding thought likely or desirable.

Our own organization—an association of industrial companies already involved in fusion work—considers the pace of further development efforts to be limited by the funds available rather than by science and technology. In the same vein, the Fusion Advisory Panel says, "The primary problems facing expeditious development of fusion power are not at present technological, they are institutional." Both agree that the timetable can and should be moved up, so that fusion power becomes commercial by the end of the century. This was the sense of the legislation passed by both houses of Congress in 1980. All that is needed now is the funding and the institutional organization to move ahead.

Edited by Sheldon D Strauss

Casting Fusion Adrift

by Edwin E. Kintner

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Casting Fusion Adrift

by Edwin E. Kintner

The nation's pace-setting program for exploiting the ultimate energy resource is in danger of going under.

The development of fusion energy has reached a critical point. There is now a consensus: We can safely assume our ability to generate and contain plasmas under conditions we believe will make possible commercial energy production. We should now proceed in earnest to develop the engineering technology required to refine this scientific achievement for practical use.

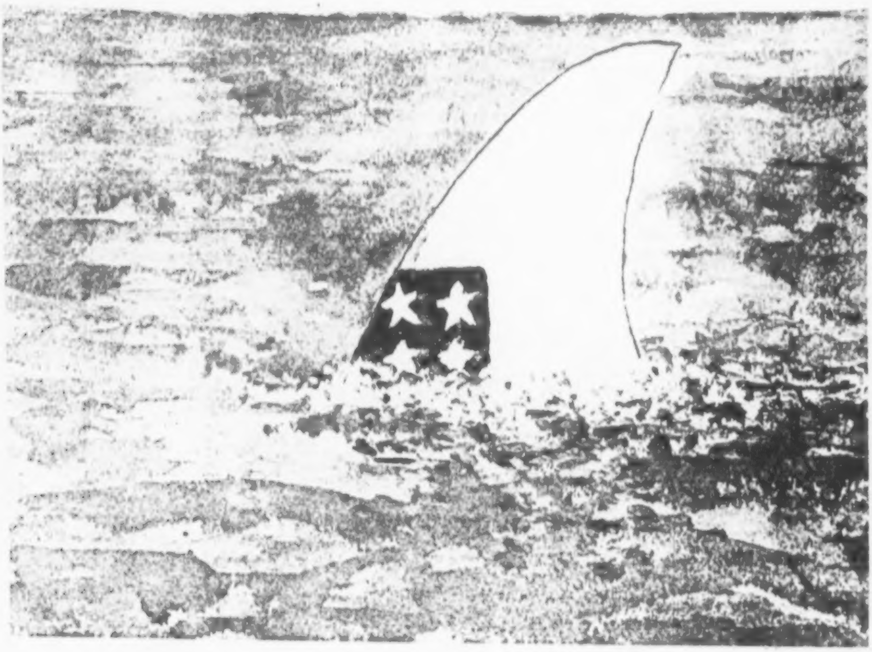
But ironically, that judgment has been reached in the U.S. just when federal discretionary funding, especially for energy research, is being sharply restricted. As a result, the technological development

of fusion, although already planned by the Department of Energy and mandated by Congress, will be delayed indefinitely.

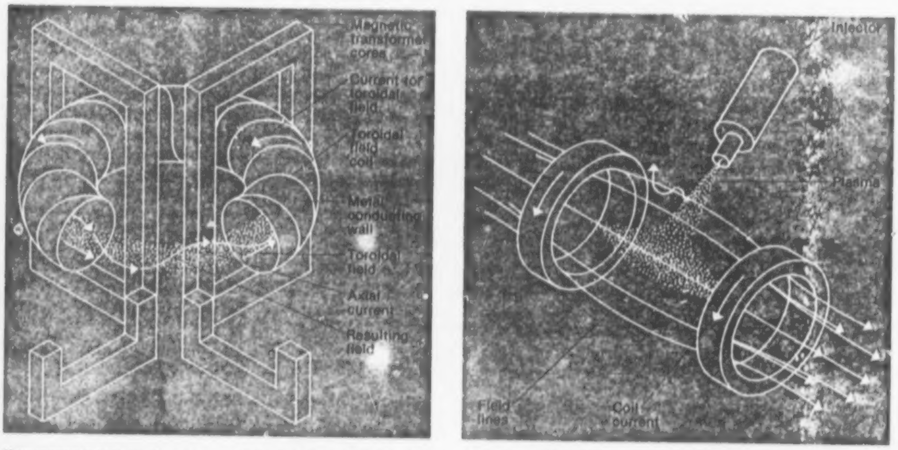
To understand the implications of this decision, it must be put in the context of our overall energy circumstances and the potential contribution of fusion.

Energy is a crucial variable in the future of modern civilization, the sine qua non of industrial society. Energy provides light in darkness, heats our homes, and cooks our food. It is necessary for the production of goods, rapid transportation and communication, and modern agriculture and food processing. Its rising cost in the past decade has already slowed the economies of all industrial nations, and its geographical distribution increasingly influences diplomatic and military decisions. The most important potential trigger for thermonuclear disaster is competition for energy, and its cost and availability have become the dominant factor in Third World development.

Industrial societies have now made use of all known energy resources except fusion, and the availabilities, cost, and effects of these conventional resources are relatively well known. Fossil fuels are finite in quantity and produce negative environmental effects;



Even if the research
goes reasonably well, that achievement would
require the expenditure of
about $15 billion.



How magnets confine plasmas in the two most promising fusion systems. At fusion conditions all materials are plasmas, composed of electrons and dissociated ions, both of which tend to rotate around magnetic field lines. The goal of both systems is to arrange magnetic fields so that they efficiently confine and insulate the plasmas. In the tokomak device, current in a toroidal field coil creates a strong magnetic field that defines a "doughnut" through which the plasma flows. In the mirror device, circular magnets create a bundle of field lines compressed at the ends.

solar energy is useful but limited. Even if nuclear fission, including the breeder reactor, is fully utilized, the United States faces an energy shortfall within the next two decades. There is a vital need for an additional large-scale energy resource.

Controlled thermonuclear fusion meets that need. It offers greater flexibility in end products and brings with it only modest environmental threats, and it uses a benign natural resource: water. If fully developed and successfully deployed, fusion could greatly ease world energy problems indefinitely.

Under these circumstances, it is unthinkable not to deliberately but aggressively continue to develop fusion to practicality. The price of failing to do so will not be paid for many years—perhaps decades—but it will be very high. This is true even if the effort proves unsuccessful, because we will more clearly understand our limits and can better plan the use of our remaining energy resources.

How Matter Becomes Energy in the Fourth State

The goal of the fusion process is to bring together the nuclei of two or more elements under conditions where they fuse together, releasing significant quantities of energy. Since vast energies must be imparted to the nuclei, the lighter elements—especially the isotopes of hydrogen known as deuterium and tritium—are preferred. This fusion process does not release particulates or gaseous effluents. The total radioactivity generated is expected to be one-hundredth to one-thousandth that of a fission reactor producing the same power. The radioactivity is also more benign than that in fission reactors; there are no fission products such as strontium and iodine that pose special health hazards.

The most significant element of radiological concern is the tritium fuel. Tritium has a relatively short radiological half-life (14 years) and a much shorter biological half-life (approximately 12 days), and therefore poses a very different threat from that of the waste products of a fission reactor. A fusion reactor would lack sufficient fuel for a runaway nuclear explosion and contain insufficient residual heat for a core meltdown.

To fuse, the nuclei of light elements must be heated to very high temperatures—around 100 million degrees, or five times the temperature of the sun's

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and successfully deployed, fusion could greatly
ease world energy problems
indefinitely.

core—and confined at high pressures. Under these conditions, all materials are plasmas—the so-called "fourth state" of matter in which electrons are dissociated from their nuclei. Such a mixture of charged particles can be confined in one of three ways: by gravitational fields such as those of the sun and stars, by inertial reactions as used in thermonuclear bombs, or by magnetic fields. The first method is impractical on Earth because it requires masses as large as the planet Jupiter. The second is being investigated as a part of U.S. defense research. The third—the most practical—is the subject of the Department of Energy's magnetic fusion program.

Present systems for magnetic confinement of plasmas are based on the fact that charged particles such as ions and electrons tend to rotate around magnetic field lines. Thus, to confine plasmas, scientists seek to construct containments of such field lines—either in doughnut-shaped forms (toruses) or bundles of lines squeezed together at their ends (mirrors). But the confinement is temporary; even with very strong magnetic fields, the plasma particles tend eventually to drift across the field lines and escape. The problem is to find arrangements of magnetic fields in which plasmas can be confined and heated enough to reach the temperatures and pressures adequate for fusion with a net energy gain.

Developing and commercializing this process is a difficult technical task. Fusion research has been underway for 30 years, and another 20 years may be required before its practical usefulness is actually first demonstrated. Even if the research goes reasonably well, that achievement would require the expenditure of about $15 billion. These requirements of time and money are not easily met by a political system that tends to emphasize fast payback, low risk, and flexibility. This difficulty is probably fusion's greatest problem.

Though fusion energy is many years away, our investment in the strong, aggressive program begun during the crisis of the oil embargo of 1973 has brought significant returns. The United States has assumed prestigious world leadership in this advanced scientific field, a leadership held until 1973 by the Soviet Union. This effort has resulted in new developments in many areas in addition to high-temperature plasmas, including superconducting magnets; high-temperature, irradiation-resistant materials; high-voltage, high-power electrical equipment; and mathematics and computational techniques. This advanced work has already yielded valuable industrial spinoffs that have helped maintain U.S. technological leadership and economic strength, and fusion research and development will continue to have this kind of payoff in the future. In fact, no other energy or defense program contributes as strongly to broad, long-term research needs—the kind of support provided in past years by nuclear energy, radar, and space research. This continued leadership has substantial practical value for the United States, especially in a period when the country's technological position seems to be eroding.

A Decade of Ever-Increasing Optimism

The fusion program began in 1951, when a number of scientists, notably Lyman Spitzer at Princeton, noticed that magnetic fields diverted and constrained plasmas in solar flares and the aurora borealis. It was a time of great confidence in nuclear science spawned by the successful development of nuclear weapons, and the problem of confining plasmas at high temperatures and densities for the fusion reaction was tackled with optimism.

But by 1959 there was growing pessimism. Instead of acting as a mixture of discrete particles as early researchers had assumed, plasma exhibited collective electrostatic and magnetic instabilities that allowed it to escape from the confines of magnetic field lines. By 1965 these problems seemed so difficult that a review committee of the Atomic Energy Commission recommended that modest research be continued only in a few carefully delineated directions.

But four years later, the Soviet physicist L. Artzimovich brought to M.I.T. information about plasma containment in a new device called the "tokamak." The Soviets used the same toroidal magnetic-field configuration studied in the U.S. for many years, but they induced a very high current—hundreds of thousands of amperes—in the conducting plasma. The resulting magnetic field around the torus had a helical shape that greatly improved its ability to contain the plasma at higher pressures and temperatures.

U.S. physicists immediately turned to tokamak research and confidence soon grew. Indeed, by 1973, as part of Nixon's Project Independence, the U.S. embarked on a strengthened fusion program with the tokamak confinement concept as its central thrust.

The U.S. program has since progressed rapidly, with almost continuous exponential improvement in all the main aspects of fusion confinement. Scientists have now obtained temperatures in the area of con-

Controlled thermonuclear fusion brings only modest environmental threats and uses a benign natural resource.

finement of 80 million degrees. (The minimum ignition temperature is 45 million degrees, and 100 million degrees is necessary for a practical reactor). The degree of confinement of the plasma by magnetic fields is now within a factor of 5 to 10 of that desired for a practical reactor, and the laws of plasma confinement are now sufficiently understood so that remaining improvement can be assumed. In fact, three experimental tokamak devices expected to generate and contain plasmas at the conditions required for a power reactor—the Tokamak Fusion Test Reactor at Princeton, the Joint European Torus at Culham Laboratory in England, and the JT-60 in Japan—are now under constuction.

The effort to develop a "mirror" of magnetic-field lines to confine the plasma has also made remarkable progress in the last two years, and a comparison between tokamaks and mirrors should be possible by the mid-1980s. There are also efforts to develop several smaller confinement systems. The most important is the Elmo Bumpy Torus in which a number of mirror cells are arranged in a toroid so that the losses from one cell are picked up in its adjoining cells.

Obviously, the intent of the U.S. plasma physics program has not been to press forward at maximum speed by concentrating only on tokamaks as the lead concept. Rather, the goal has been to generate a broad spectrum of knowledge of plasma confinement by magnetic fields so that the we can select the best, most useful arrangement and then efficiently perfect it.

The plasma confinement problem can be thought of as a giant jigsaw puzzle. As scientists gain additional understanding, they are able to gather its pieces together in clumps, some of which—such as the tokamak clump—are larger than others. Just as progress accelerates as the jigsaw puzzle nears completion because remaining pieces fall into the puzzle more rapidly, so progress is accelerating in plasma containment. The several lines of plasma-physics development have converged, and now much of what has been learned about mirrors or tokamaks or Elmo Bumpy Toruses is directly useful in the other confinement concepts. The experimental devices now in place or under construction, and the relatively inexpensive modifications possible over the next decade, should give us the insights necessary for fusion to become a practical success. We will need continued research for the rest of the century to reach highest efficiencies, but a successful end can be predicted with great confidence.

An Unprecedented Technological Challenge

With this assurance we can begin to work in earnest on the new engineering technologies involved in fusion reactors. There are two main objectives: to provide the higher-powered magnets, plasma heaters, and instrumentation for continued advances in plasma-physics research; and to solve the major technological problems in building practical, power-producing reactors using the fusion principle. These engineering tasks will probably require greater effort than the purely scientific development now coming to fruition.

The U.S. program in magnetic confinement, which has already provided the basis for the recent success in plasma temperature and pressure, is the strongest in the world. Meanwhile, our technology program has made a good start by identifying many engineering requirements, and some preliminary programs and facilities to fulfill them are now in place or planned.

The foremost engineering challenge involves structural materials. Almost without exception, new technologies succeed or fail because of materials. Jet aircraft would have been impossible without lightweight, strong aluminum alloys and high-temperature materials for engine blades, fission energy required the development of zirconium and its alloys as fuel cladding materials, space exploration was based on the development of a variety of new materials for rocket engines and ablation shields, computers and modern electronics were made possible by the development of semiconductors. Most of these materials will be essential in fusion technology.

There will also be new and difficult materials challenges: the environment surrounding a burning fusion plasma will contain large concentrations of high-energy neutrons, and no materials now exist that adequately resist deterioriation by high-energy neutron fluxes. In addition, materials are needed for blankets and shields, between the plasma wall and the magnet structure of the fusion reactor, that can absorb and transmit the heat to the power-producing machines while protecting the magnets and breeding tritium fuel. Studies of the engineering requirements for these components are only now beginning.

Obtaining economical fusion energy will also depend upon constructing superconducting magnets of larger size and power than have yet been built. A good start has been made in the development of magnets for the T-7 tokamak in the Soviet Union and for other fusion machines in the United States, and it now

Our investment in a strong fusion program began during the Arab oil embargo of 1973 and has already yielded significant industrial spinoffs.

appears that such magnets can be built. However, a great deal more development and operating experience will be needed.

An operating fusion power reactor will become radioactive—not as strongly as the core of a fission reactor, but enough so that maintenance and repair will have to be done remotely or from behind radiation shields. This problem will be encountered for the first time with the Tokamak Fusion Test Reactor now under construction at Princeton, and considerable development will be required before fusion power reactors can be properly maintained.

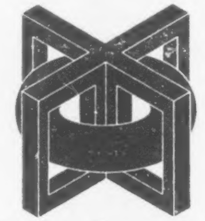
A Congressional Mandate

The recent advances in plasma confinement and the resulting increased interest in fusion have led to a number of independent reviews of the fusion program. The first was initiated by the Department of Energy in 1978 and chaired by John Foster, former head of research and development in the Department of Defense who is now vice-president of TRW. Among the conclusions of this group: "The first objective of the program must be to determine the highest potential of fusion as a practical source of energy. There is an urgent need to answer the questions concerning feasibility, and . . . there must be a major increase in emphasis on engineering problems to provide the basis for proceeding to the choice of a prototype reactor."

The Department of Energy responded to these recommendations with a Policy Statement on Fusion, the first of its kind on any energy technology: "There is no lead time to spare. If fusion energy is to be available when it is needed, the research and development program, rigorously directed toward the goal of commercial utility, must be undertaken in earnest now."

Following these recommendations, the magnetic mirror program was strengthened by a decision to build a major test facility, and an experimental Elmo Bumpy Torus facility was also launched.

In early 1980, Congressman Mike McCormack, chairman of the House Subcommittee on Energy Research and Production, organized a Fusion Advisory Panel of distinguished scientists to hold special hearings on the status of the U.S. fusion program. The panel concluded that "very significant recent technological progress in fusion research" warranted "an engineering thrust centering on an engineering test facility. . . . Our panel believes that fusion can be



Six Policy Imperatives for Fusion Success

GIVEN present constraints, what should be done to assure an effective program to assess and develop the future contribution of fusion to world energy needs?

The following six steps are essential:

☐ A wider public understanding of our present and likely future energy situation, and the significance of fusion within that context, must be encouraged. Such public understanding can be developed only with the active participation of all media and by unremitting efforts of knowledgeable citizens in all parts of society. It is surprising and troubling that fusion has no vocal proponents at influential levels of American life.

☐ A new strategic timetable for fusion development, dictated wholly by technical objectives and not short-term political considerations, should be established as soon as possible. The plan should emphasize pursuit of all aspects of fusion engineering research, including a Fusion Engineering Device.

☐ The United States should take the lead in making fusion an international project by sharing its knowledge with other nations and delegating responsibility for some research areas. Fusion research could provide a unique precedent for international technical efforts in many fields of common concern, such as acid rain and the buildup of atmospheric CO_2.

☐ Industrial participation in fusion research should be encouraged and expanded. If fusion is to contribute to industrial technology and become a practical energy resource, industry must be involved, especially if it is to make large investments of capital and personnel.

☐ The fusion program should develop a strong organizational structure independent of short-term energy programs in sponsorship and funding. Fusion has not done well in competition with other energy technologies and science programs because it does not promise immediate—or even certain—benefits.

☐ The safety and regulatory programs governing fusion must be independent of those controlling fission reactors and not simply an addition to existing programs of the U.S. Nuclear Regulatory Commission. The safety concerns of fusion are unique, and experience and practices with present reactors would not be appropriate precedents.—*E.E.K.* ☐

made commercial before 2000 if a national commitment is made soon."

The Department of Energy chartered another thorough scientific review of the magnetic fusion program later in 1980, this time by a panel headed by Solomon J. Buchsbaum, vice-president of Bell Telephone Laboratories who was then chairman of the DOE's Energy Research Advisory Board. A broadly experienced group of scientists and engineers, the Buchsbaum panel has been called "the most powerful group of its kind ever assembled for a scientific program review." Its major recommendation was that "a broad program of engineering experimentation and analysis under the aegis of a Center for Fusion Engineering" be established to achieve economically feasible magnetic fusion.

A key element of the program would be construction of a Fusion Engineering Device to "provide a focus for developing and testing reactor-relevant technologies and components" and to help "explore and firmly delineate problems of operator and public safety." Such a device should be in operation within ten years, the Buchsbaum panel said, and the cost was estimated at "not more than" about $1 billion (in 1980 dollars). Achieving these goals, said the Buchsbaum panel, would require "a doubling in the size of the present fusion program in five to seven years."

Following this report, the U.S. Congress enacted the Magnetic Fusion Energy Engineering Act of 1980, which declared that U.S. policy is "to accelerate the national effort in research, development, and demonstration activities related to magnetic fusion energy systems. . . . To ensure the timely commercialization of (such) magnetic systems, the United States must demonstrate at an early date (their) engineering feasibility." The act recommended 25 percent increases in magnetic fusion budgets in each of the first two years of the new program.

With the coming of the tokomak in 1969, fusion had been given mission orientation; the goal was—naively, I think—to compete with other energy forms in the commercial market at the earliest possible time. But this simplistic approach failed to reflect the technical difficulties involved in obtaining energy from fusion. The studies of 1978-80 were far more sophisticated. They focused on the vital issue of determining as soon as possible whether fusion can be counted on as a long-range energy resource, and they set as the major near-term goal the confirmation of both the scientific and technical feasibility of fusion by the early 1990s.

Technology Lost in the Budget Battle

Recent implicit and explicit decisions have dimmed the prospects that the strategy and timetable mandated by the Energy Engineering Act can be carried out.

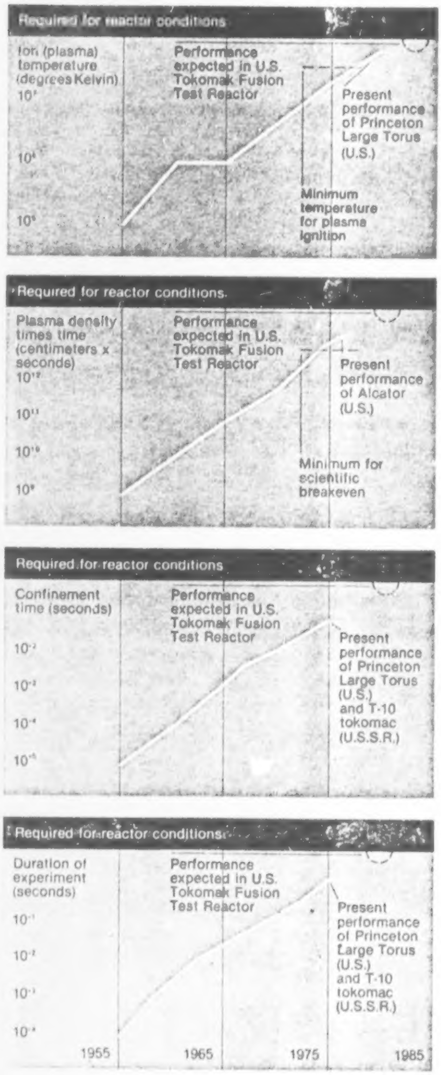
The initial budget request by the Magnetic Fusion Program Office for 1981-82 was $525 million. This included strong support for two new projects in the scientific program—proof of the Elmo Bumpy Torus principle and construction of an Advanced Toroidal Facility to consolidate what has been learned about tokamaks and other toroidal systems worldwide. It also included funds for construction of a Fusion Materials Irradiation Test (FMIT) Facility, the only project anywhere in the world capable of irradiating materials at the high neutron energies and fluxes of fusion reactors, and $33 million to establish a Center for Fusion Engineering and begin in earnest the design of the Fusion Engineering Device.

The Office of Management and Budget reduced this request by $18 million before it went to Congress as part of President Carter's 1981 budget, and it was later further reduced by the Office of Management and Budget to meet the Reagan administration's guidelines. Thereafter, a series of step-by-step reductions in fusion budget plans for 1981-82 and 1982-83 made it clear that the strategy and timetable for fusion set forth by the 1978-80 studies could not be maintained. The amount available in the 1981-82 budget for the Center for Fusion Engineering was cut to $9.1 million, allowing only for organizational expenses and conceptual design activities. The new proposals effectively canceled the Fusion Materials Irradiation Test Facility, despite the fact that materials development has been recognized for years as the most difficult, longest-term technological problem in fusion. The Elmo Bumpy Torus program received sufficient funding to move ahead at half pace, but the new initiative in toroidal confinement was canceled. Congress reinstated $14 million for the FMIT, and the 1982 fusion budget was settled at $456 million.

The initial request by the fusion program office for 1982-83 was for $596 million. At this level, all the steps required by the Magnetic Fusion Energy Engineering Act could have been modestly reinitiated, including establishing the Center for Fusion Engineering, beginning the long-term research to obtain competitive designs for a Fusion Engineering Device, and continuing a strong physics program.

The Department of Energy's review of these pro-

Thirty years of progress in magnetic fusion energy research. All four of the conditions believed necessary for the self-sustained fusion reaction required for useful energy production are now being approached under laboratory conditions, and successful achievement of all four is predicted with great confidence. There remains the task of developing the technology to harness these extraordinary reactions in machines of commercial scale.



posals in June 1981 continued to embrace the goal of determining "the engineering feasibility of fusion energy during the next decade." But it was understood that while DOE would do engineering work, it was "not prepared to commit to the construction of a Fusion Engineering Device at this time." Accordingly, an 1982-83 budget of $557 million, about 10 percent above the 1982 budget, was proposed—the minimum required to hold to the basic strategy of the Magnetic Fusion Energy Engineering Act, although at a much reduced pace. The large increases in expenses visualized by the act were delayed beyond FY 1985. As the program director, I believed that this proposed 1983 program balanced the need to reduce expenditures with the strong program recommendations made by the review panels and enacted by Congress.

Now, however, with no formal hearings between the Department of Energy and the Office of Management and Budget, the 1983 budget has been presented to Congress with a total of $444 million for the fusion program. This is 25 percent less than the 1977 budget in real terms.

That amount allows for continuation of present laboratory activities, including the tokomak at Princeton. Indeed, most existing experimental efforts and many activities in the plasma physics program may be overfunded. But the $444 million does not provide for the broadening of activities recommended by the Foster committee nor the engineering initiatives recommended by the Buchsbaum panel and authorized by Congress. The 1983 budget provides only sufficient funds to keep a small design team working on the Elmo Bumpy Torus project; it provides no funds for the Advanced Tokamak Facility. It puts the Fusion Materials Irradiaton Facility "on the shelf," although over $60 million has already been spent for its design and development, and there are no funds to actively plan for the establishment of a Center for Fusion Engineering or a Fusion Engineering Device.

Finally and most important, the 1983 budget removes $25 million from the funding profile for the major mirror machine. If similar amounts are removed over the next two years as well, as implied by OMB actions, the mirror machine will be delayed by almost three years.

Two fundamental program decisions are implied in these changes. The first is to forego, for an undetermined but extended period, the strategy and schedule recommended by the Buchsbaum panel and incorporated in the Magnetic Fusion Energy Engineering

Recent budgetary decisions leave the fusion program without a strategic backbone.

Act of 1980. (Senior officals in the Department of Energy characterized this act as "permissive" and "a silly piece of paper.") The second is to delay the major mirror facility by up to three years and, therefore, to postpone by at least that long the comparison between toroidal and mirror systems.

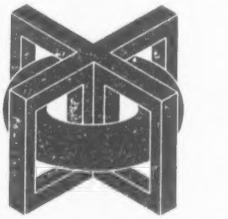
Those decisions leave the fusion program without a strategic backbone—it is a collection of individual projects and activities without a defined mission or timetable. The plan to increase industry involvement in fusion development is postponed indefinitely, and the industrial and economic benefits of high-technology spinoffs, surely an increasingly important byproduct of an accelerated fusion technology program, will be lost. These spinoffs could have been expected in areas such as vacuum tubes handling higher power and frequency than any previously developed, new superconducting materials, metals of higher irradiation resistance, robotics, and new computational techniques.

In sum, these budgetary actions redirect fusion research enitrely away from the practical engineering developments that could prove critical when fossil-fuel reserves are exhausted.

Why this sudden reversal in national policy? The obvious answer is that proceeding as planned requires a mortgage on the future at a time when the administration's overriding objective is to reduce such commitments. But there are gross inconsistencies between this thrust and the administration's stated energy policies. The National Energy Plan as forwarded to Congress by President Reagan says: "There is an appropriate federal role in certain long-term research. . . . [to bring] promising technological innovations to the point where private enterprise can reasonably assess their risks. . . The federal government recognizes a direct responsibility to demonstrate the scientific and engineering feasibility of fusion."

The administration's recommendations for other research programs in the Department of Energy (high-energy physics, basic energy sciences, and nuclear physics) generally were consistent with this policy statement. Only the technology programs—solar, synthetic fuels, fusion, and others—have been grossly weakened.

These budget reductions would be more readily understandable if the magnetic fusion program were failing, but the last several years have seen rich experimental and theoretical advance, with more promise for the achievement of practical fusion energy than ever before. These advances represent the start of an invaluable return on the investment the United States



Synthetic Fuels Through Fusion

Of all the fossil fuels, petroleum and natural gas are most in demand and most limited in supply. Substitutes for them will have to be found if we are to avoid future worldwide institutional and social disruptions early in the next century, perhaps sooner. Since many years are required to develop and implement major new technologies, serious studies of all potential alternatives for producing substitute forms of liquid and gaseous fuels must be undertaken now.

As I point out in the accompanying article, fusion is perhaps unique as a potentially inexhaustible major energy source. Its fuel is deuterium and lithium—the former available in seawater, the latter in widespread granite and brine deposits. Two reaction paths are followed in a fusion reactor. The deuterium-tritium reaction produces a helium atom and a highly energetic neutron. The deuterium-deuterium reaction produces either a helium nucleus and a moderate-energy neutron or a tritium atom and a proton. Some or all of the tritium then reacts with deuterium to produce a substantial number of the high-energy neutrons. These high-energy neutrons, carrying 80 percent of the energy from the fusion reaction, are highly penetrating, and will be captured by an absorbing blanket surrounding the reacting plasma chamber at some distance from the plasma.

This means that fusion reactors will have a unique characteristic—they will deliver their principal reaction energy at a distance from the reacting plasma, and this will make it possible to decouple the energy production and conversion systems. The blanket can be designed with operating characteristics essentially independent of the plasma and the requirements for its confinement and reaction. Thus, a blanket design could be developed that focuses almost exclusively on the special requirements of synthetic fuel production.

The key to the production of synthetic fuels is hydrogen; it is the essential ingredient that must be added to coal in converting it to liquid or gaseous synthetic fuel. Two interrelated processes would use the high-temperature heat

The day when fusion can make a significant contribution to world energy resources will be delayed indefinitely.

has made since 1973. A doubling of the present fusion budget from $400 million to about $800 million annually over a five-to-seven year period seems a modest investment considering past progress and the historic implications of fusion.

Delaying the Fusion Era

What are the consequences of this decision to turn away from a comprehensive program for the development of fusion as a practical energy resource?

☐ Strong U.S. leadership in the world's fusion program will be seriously weakened. The U.S. program, although only one-third of the world effort, exerts significant leverage on the remaining two-thirds. The effectiveness and confidence with which the United States has carried out its program since 1973 has stimulated fusion research everywhere, especially in Japan. With the possible exception of the Japanese, world programs will slow down in response.

☐ Divisive forces will surface within the U.S. program: one confinement concept versus another, one laboratory versus another, science versus engineering, industry versus national laboratories, national versus international objectives. In a time of consensus, competition is a source of strength. But in a time of restricted funding, it may become a point of controversy.

☐ With their strategic plan abandoned and additional budget cuts, researchers will be hard pressed to maintain morale and progress even toward reduced goals. The diminished short-term industrial payoffs from fusion development will likely lead to additional attempts to restrict the fusion program's objectives to science-oriented activities.

☐ Most important, the day when fusion can make a significant contribution to world energy resources will be delayed indefinitely.

Must the United States abdicate its leadership role? Must we fail to aggressively pursue the development of the world's last energy resource because our social and political systems lack the will and vitality to accept such a challenge? If we do not now proceed deliberately and vigorously with the development of the engineering side of fusion, the future will *look* different within 10 years and will *be* different within 25.

Edwin E. Kintner resigned early this year after five years as director of the Department of Energy's Office of Fusion Energy in protest over the programatic changes described herein. He has been associated with navy and civilian nuclear power programs since receiving master's degrees in naval engineering (1946) and nuclear physics (1950) from M.I.T.

from a fusion reactor to produce hydrogen by dissociating the hydrogen and oxygen atoms in water. These processes include thermochemical cycles, in which the energy required to break the chemical bond in the water molecule is supplied directly as heat from the reactor; and high-temperature electrolysis, in which electrical energy is added to the thermal energy needed to dissociate the hydrogen and oxygen.

A study at Brookhaven National Laboratory of a high-temperature electrolysis plant, driven by a tokamak fusion power reactor with a blanket at temperatures above 1000°C, suggests that production of approximately 1,000 metric tons of hydrogen per day is possible. That amount is equivalent to 20,000 barrels of oil if burned directly as fuel, and 40,000 barrels if used to convert coal into synthetic oil. At the same time the reactor would breed tritium in a lithium blanket to sustain operation of the fusion reaction itself.

The overall efficiency of the process, in terms of the energy gained from the fusion reaction compared with the chemical energy of the hydrogen product, is estimated at 50 percent. Conventional electrolysis using fusion-generated electricity could readily be used to decompose water, but this system would be far less efficient because of the limitations inherent in the production of electricity by low-temperature electrolysis.

In addition to providing an efficient source of hydrogen, fusion could also provide the substantial thermal energy required with the hydrogen for converting coal to synthetic liquid or gaseous fuels. With fusion supplying this conversion energy at higher temperatures than can be attained from other sources, the amount of synfuel produced from a given quantity of coal could be increased by a factor of two to three. At the same time, the environmental impacts (including release of carbon dioxide) of coal combustion would be reduced by a similar factor.

As I point out, research on fusion technology for practical use is well underway. We confidently expect the demonstration of energy break-even conditions in a fusion reaction between 1985 and 1990.

If fusion development is now pursued aggressively, a demonstration of technical feasibility, including substantial fusion power production in a high-temperature blanket, could occur in the early 1990s. Following further development and scale-up, the commercial feasibility of using high-temperature blankets for the production of synthetic fuels from fusion could be demonstrated early in the twenty-first century, just when supplies of liquid and gaseous fossil fuels are being seriously depleted.—*E.E.K.* ☐